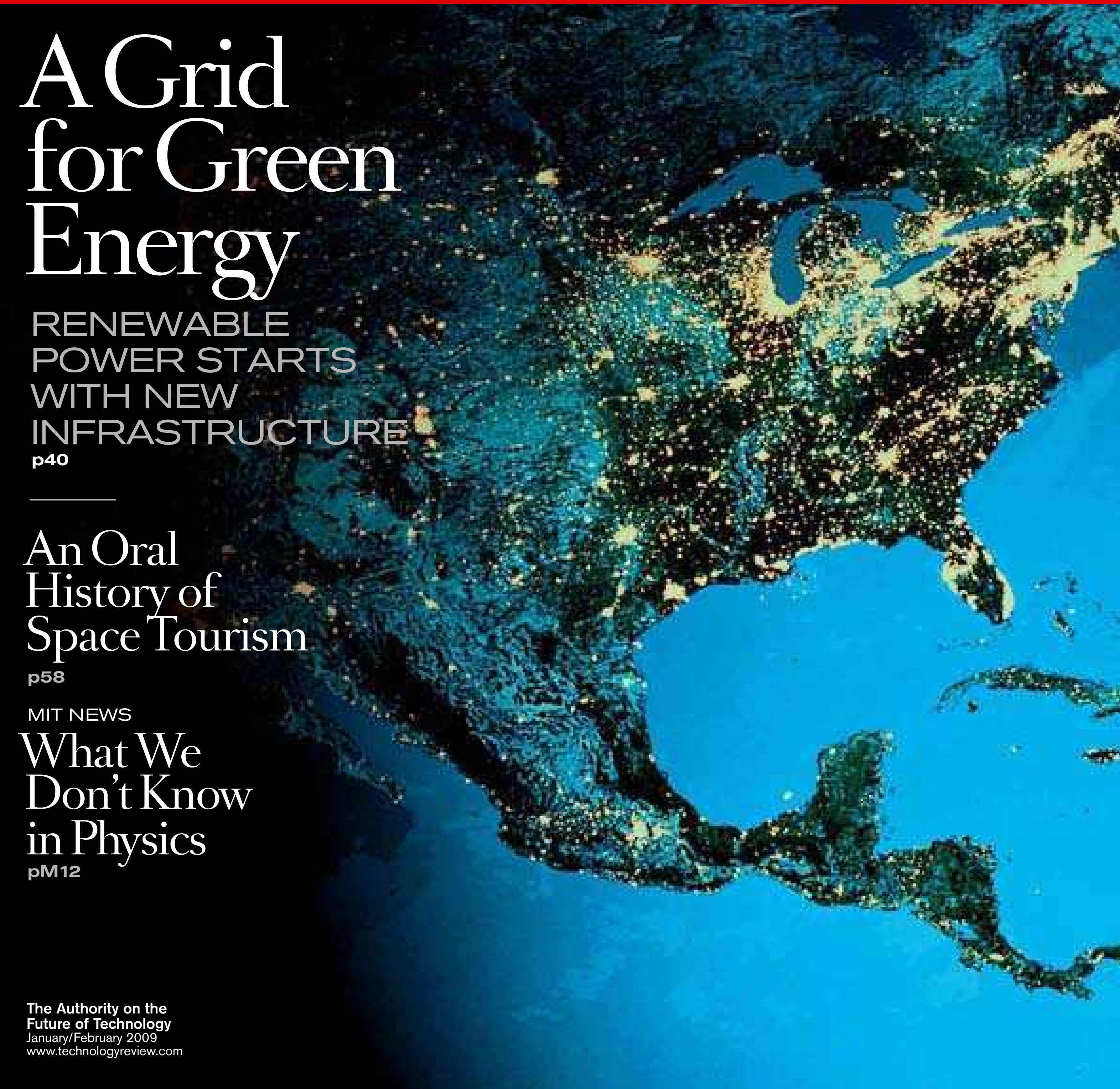
YOUR PERSONAL GENOME FOR $1,000
p48

Technology Review

PUBLISHED BY MIT SINCE 1899



A Grid for Green Energy

RENEWABLE POWER STARTS WITH NEW INFRASTRUCTURE
p40

An Oral History of Space Tourism

p58

MIT NEWS

What We Don't Know in Physics

pM12

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January/February 2009
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– John Weilandt, Chief Technologist, NSTAR

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80

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Northwest
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France
Philippe Marquezy
philippe.marquezy@espacequadri.com
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Germany
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49-511-5352-167

Europe
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mail@afitzgerald.co.uk
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Japan
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One Main Street, 7th Floor
Cambridge MA 02142
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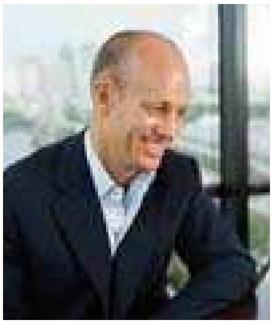


MARK OSTOW

The Geological Strata of Things

OLD TECHNOLOGIES SELDOM DIE; THEY GET UPGRADED.

Mark Shuttleworth, a South African Internet tycoon who paid tens of millions of dollars to go to the International Space Station aboard a Russian Soyuz craft, recounts his arrival in space—blinking, wondering, and weightless after the fire, shaking, and acceleration of liftoff—in Adam Fisher's oral history of space tourism *("'Very Stunning, Very Space, and Very Cool,'" p. 58)*:

> The thing I remember as being quite striking was this collection of very domestic sounds that kicks in after the main-engine cutoff. Mechanical sounds, like the air circulation and the conditioning, and then bits and pieces are kind of kicking in. You've got alarm clocks and fans, and you've got a big device called the "globus." It's a ball—your map, basically—that turns, and it starts going *tick, tick, tick*, like a cuckoo clock. You've just gone through this extraordinary experience of getting into space, and then suddenly it's like waking up inside the workshop of an old Swiss clockmaker or something. So it's this amazing contrast between what you might expect—which should involve special effects and background music—and the very mechanical physical reality of it.

Thus, even the most transcendental of real, human experiences (which Saul Bellow, in *Mr. Sammler's Planet*, evoked, wonderfully: "To blow this great blue, white, green planet or to be blown from it") occurs amid the most mundane technology.

That technology can be very old. The space tourist Charles Simonyi, a former Microsoft executive responsible for Word and Excel, whom we profiled two years ago *("Anything You Can Do, I Can Do Meta," January/February 2007)*, describes the optical sight on the Soyuz: "It's like a very old-fashioned—I don't know what it is. There is nothing, no items like that any more. ... That instrument could have been constructed in the 19th century."

Famously, the Russian space program employs a brutalist approach: its engineers use the crudest, oldest technology that works. (Since the first Soyuz flew in 1966, only those parts that have failed or are obviously obsolete have been redesigned.) But the technology aboard the space station, much of which was constructed by the U.S. and European space agencies as well as the Russian, is only a little shinier. Simonyi says, "The space station is so messy. Words don't do justice. It's like going into the messiest hardware store you have ever seen."

Because they are professional futurists, technologists like to contemplate new, bright, and disruptive technologies. Often, by a process of substitution, they talk about the newest iterations of things as if they were the only things people actually use. But our spaceships disclose a universal truth: old technologies are seldom abandoned, and only when they are intolerably inconvenient. (The former financial analyst Pip Coburn calls the moment when a "perceived crisis" is worse than the "perceived pain of adoption" of a new technology the "Change Function": see "Who's Sorry Now?", May/June 2006). Mainly, however, old technologies accumulate like geological strata, changing under the pressure of new circumstances.

The writer Robert X. Cringely has succinctly expressed this idea in one of his "laws of computing": "Old software never dies; it just gets upgraded." In "Parallel Universe" *(p. 54)*, Cringely explains how multicore computing—the use of many microprocessors on a microchip—can multiply processing power without increasing the heat associated with ever-greater miniaturization. Cringely writes that in order to solve some of the problems of parallelism (or how software is torn apart so that a process can be run in parallel on hundreds of processors), Intel has recalled to service "some graybeards of 1980s supercomputing." For these graybeards, parallelism never disappeared. Now, in order to preserve Moore's Law, we will use technologies first developed to build nuclear bombs during the Cold War.

Or consider the U.S. electrical grid. In our cover story, "Lifeline for Renewable Power" *(p. 40)*, our chief correspondent, David Talbot, writes, "A patchwork system has developed. ... But while its size and complexity have grown immensely, the grid's basic structure has changed little since Thomas Edison switched on a distribution system serving 59 customers in lower Manhattan in 1882." Talbot shows that the old grid, constructed to transmit the predictable flow of electricity from the burning of fossil fuels, must be upgraded if it is to accommodate more-variable, renewable energy sources like wind and solar power.

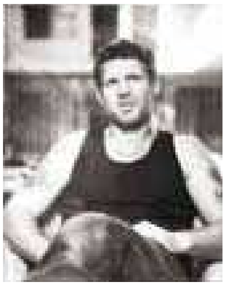
As much as they are a deepening coastal shelf beneath our technological civilization, old technologies also live in each of us. Biologically, we are their creatures. Explaining how archaeogenetics, the application of genetic analysis to the study of prehistory, might explain the puzzle of how we came to be highly civilized creatures *(see "Our Past Within Us," p. 74)*, Mark Williams argues that we evolved through our technology. "Humankind invented agriculture, started eating different foods, and began dwelling in cities; populations expanded, allowing large numbers of mutations. Natural selection promoted the spread of beneficial variations." Among those traits selected, Williams suggests, were those that allowed us, eventually, to build spacecraft and space stations. But write to me and tell me what you think at jason.pontin@technologyreview.com. *—Jason Pontin*

ADAM FISHER spent months compiling an "oral history" of a rarefied experience: private spaceflight (*"'Very Stunning, Very Space, and Very Cool,'" p. 58*). Since 2001, when former NASA engineer turned financier Dennis Tito flew to the International Space Station aboard a Russian Soyuz spacecraft, five more people—at a price of around $30 million apiece—have made similar journeys. "I waited for six months to interview some of them," says Fisher. "They are all smart, charismatic, and well spoken—the kind of people you want to be seated next to at a dinner party. It was only later, when I played back the tape of my interviews, that I realized that they were talking about pretty personal stuff: their preflight enema, for example, or what happens when you vomit in zero G!" Fisher was a features editor for *Wired* and *New York*. He now writes about travel, food, science, and technology from a houseboat in Sausalito, CA.

EMILY SINGER reports on the trend of personal genomics, which is being made possible by rapid advances in DNA sequencing technology (*"Interpreting the Genome," p. 48*). "The capacity to sequence thousands of human genomes is revolutionizing our understanding of the genetic basis of common diseases," says Singer. In the course of her reporting, she visited the century-old Cold Spring Harbor Laboratory on Long Island for the first "Personal Genomes" conference. "The newness of the topic was palpable, as presentation after presentation raised

more questions than it answered," says Singer. "How will scientists analyze the huge volumes of data they are producing, and what does it all mean?" The event may indeed prove historic for the field of genomics; attendees likened discussions there to previous pivotal debates in the field, including those over the Human Genome Project. Singer is *Technology Review*'s senior editor for biomedicine.

ROBERT X. CRINGELY reports on the central challenge facing Intel and the rest of the semiconductor industry: silicon-based microprocessors have reached such complexity that they risk overheating if they pack any more transistors into a single-core design. One solution to the overheating problem is multicore computing, whereby multiple processors within a chip are made to work with each other in parallel. But this hardware solution presents software problems that are difficult to solve (*"Parallel Universe," p. 54*). "Many years ago, a very smart boss of mine explained to me, 'If making computer hardware is like building a house, then making good software is like building a city,'" says Cringely. "My experience writing this piece shows that to be true. The challenge of making parallel software easy to write is huge, and the penalty for failure is a stalled trillion-dollar industry. My brain still aches from trying to explain the issues involved." Cringely went to Silicon Valley in the 1970s and fell into writing about and working in the computer industry. His work has appeared in such publications as the *New York Times*, *Forbes*, and *Newsweek*. His PBS documentaries have been shown in more than 60 countries.



EWAN BURNS took photographs for chief correspondent David Talbot's feature on the tremendous importance of a revitalized electrical grid (*"Lifeline for Renewable Power," p. 40*). "It was a fun assignment, involving hundreds of miles of California desert highway," says Burns. "Where I was shooting, it was desolate—a kind of no-man's-land." Burns's work has appeared in *Portfolio*, *Audubon*, *Men's Health*, and other publications.


MIT technology insider
Best Behavior
MIT technology insider
Wave of the Future

POWER OF THE SUN

Regarding Kevin Bullis's article on MIT professor Daniel Nocera's method of deriving hydrogen from water using sunlight ("Sun + Water = Fuel," November/December 2008), I suggest going further: tap the power of the sun. Had the plug not been pulled on funding of fusion-related research, we'd be closer to having that technology. Solar, wind, and even "conventional" nuclear power are all diversions from fusion. Like Nocera, let's take a hint from nature. Stellar fusion is the universe's choice for power. Let's get smart and use it here on Earth.

Gerald Schroeder
Jerusalem, Israel

November/December '08

Your article on Nocera's work suggests that he has solved the energy problem with his implied—but only vaguely explained, and completely unquantified—improvement upon the existing commercial electrolysis of water. But the article ignores two other huge and inextricably linked problems: the high cost of generating electricity from sunlight, and the difficulty of storing uncondensable hydrogen fuel. Please restore more balanced reporting to *TR*.

Don Smith
Bolinas, CA

THE INTERNET'S VULNERABILITY

It has been months since security researcher Dan Kaminsky announced the fundamental vulnerability in the domain name system (DNS), which serves as a kind of phone book for the Internet ("The Flaw at the Heart of the Internet," November/December 2008). Unfortunately, we've still got millions of name servers—which use DNS to connect users to Web pages—that are in active use and unpatched against the vulnerability. With an effective script, a hacker can insert arbitrary data into the cache of one of these servers in about 10 seconds. I urge anyone responsible for recursive name servers that look up Internet domain names, whether directly or through a forwarder, to test them for the Kaminsky vulnerability.

Cricket Liu
Vice president of architecture, Infoblox
Santa Clara, CA

BORN ORIGINALS

In a recent editor's letter about how social technologies such as Facebook are changing our notions of who we are ("Authenticity in the Age of Its Technological Reproducibility," September/October 2008), Jason Pontin begins with a quotation from 18th-century English poet Edward Young: "Born Originals, how comes it to Pass that we die Copies?" I was stunned when I read this and delighted when people I trusted were also affected. Here in one sentence we have the mission of education: to preserve and develop that individuality we all have initially and lose so quickly. I've since used this sentence as a litmus test and have been surprised by those who've reacted casually, saying, "Yes, interesting," and then changing the subject! What a mirror this provides into one's inner mind!

Herman Jacobowitz
Philadelphia, PA

In his editor's letter on social technologies, Jason Pontin writes, of himself, "Social-media Jason Pontin, in short, is a function of my business life. I know that this identity is inauthentic." I wonder: if your business-life exchanges are inauthentic because they are incomplete, wouldn't dinner with a friend also be inauthentic because it leaves out your business life? Is a jog in the park inauthentic because it's unrelated to your other pursuits? I think that our selves are created in what we do, but that none of the things we do in themselves constitute our entire, "authentic" self. We can conceive of ourselves as becoming evident in interactions, but we have many aspects to our identity; different aspects arise in different interactions, so your Twittering involves your business self, while a dinner evokes another aspect, and so on. Even subatomic particles have more than one aspect, as do the gods in some religions.

John Branch
New York, NY

NUCLEAR TERRORISM

In his essay on the threat of nuclear terrorism ("Nuclear Deterrence in the Age of Nuclear Terrorism," November/December 2008), Harvard University's Graham Allison writes that "no nation must develop new capabilities to enrich uranium," and that there must be no new nuclear-weapons states. At the same time, he assumes that it's not possible to force the present nuclear powers to eliminate their nuclear weapons. What's missing in his analysis is the consideration of a basic question: on what basis may the international community prohibit or impose limitations on the possession or acquisition of nuclear weapons? And more generally, it's worth noting that the heart of Allison's proposal is deterrence: a military measure supported by technology and international agreements. But has he considered alternative actions? It may be beneficial to analyze the socioeconomic situations and cultures of the communities from which terrorists come, and to intervene in whatever nonmilitary ways make sense.

Michele Muscettola
Milan, Italy

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NOTEBOOKS

Expert opinion

ELECTRICITY

Rebuilding the Power Grid

CLEAN ENERGY DEPENDS ON NEW INFRASTRUCTURE, SAYS CATHY ZOI.

AMERICA IS facing unprecedented challenges—a collapsing economy, threats to national security, the climate crisis. The common thread running through them all? Our addiction to fossil fuels. So in July, Nobel laureate and former vice president Al Gore issued a challenge: generate 100 percent of our electricity from truly clean sources that do not contribute to global warming, and do it within 10 years.

Meeting this bold challenge will involve work on three technical fronts. One, get the most out of the energy we currently produce. Two, rapidly develop and commercialize the clean energy technologies that we know can work. And three, create a new integrated grid to deliver power from where it is produced to where people live *(see "Lifeline for Renewable Power," p. 40)*.

The current U.S. system for transmitting and distributing electricity is in critical need of an upgrade. It is old, balkanized, and too limited in its reach. Grid-related power outages and problems with power quality reportedly cost the nation $80 billion to $188 billion per year. And areas rich in renewable resources—like solar, wind, and geothermal energy—currently have no "highway" to move the power they generate to the markets where it is needed.

To support a dramatic expansion of these clean energy sources, we need to modernize the transmission infrastructure so that electricity generated anywhere in America can power homes and businesses across the nation. A unified national smart grid would form the entire skeleton of a modern electricity system, allowing us to efficiently carry large amounts of electricity over long distances in a network that is integrated, continuously monitored, and resistant to failure. It would allow early-evening winds off the Delaware coast to help power afternoon air conditioning in California. It would use solar power produced in Arizona to support manufacturing centers in Ohio. Households would have smart meters to help manage their electricity use and might even sell electricity—generated by roof-mounted solar panels or wind turbines, or stored in plug-in vehicles—back to the grid.

Updating our grid in this way would save money, increase the reliability of the power supply, and pave the way for a clean electricity system. And just like the building of the interstate highway system and the railroads before it, a major effort to modernize the grid would create thousands of jobs for American workers.

It is an ambitious goal, but it is achievable. We have the technology, the material, the know-how, and the ingenuity. We have the steel, we have the land, and we have the workforce. What we need now is the political will. TR

CATHY ZOI IS THE CEO OF THE ALLIANCE FOR CLIMATE PROTECTION, A NONPROFIT, NONPARTISAN ORGANIZATION FOUNDED BY AL GORE.

MEDICINE

Cancer Genomics

ELAINE MARDIS DESCRIBES HOW NEW SEQUENCING TECHNOLOGIES WILL TRANSFORM OUR UNDERSTANDING OF CANCER.

OVER THE PAST few years, new technologies have begun to unravel the genomic secrets of cancer by illuminating differences between tumors and normal tissue. High-density genotyping and gene expression arrays can quickly and cheaply scan the genome for alterations and gene-expression changes linked to cancer. Sequencing of candidate genes has uncovered cancer-specific mutations, and other assays have identified changes to the higher-order structure of DNA and its companion proteins. Using statistical analysis to pinpoint the biochemical pathways affected by these changes allows us to untangle the complex interplay of cell regulation, cell signaling, and other functions that transform a normal cell into a cancerous one.

Yet three difficulties arise in such endeavors. Searching candidate genes rather than the whole genome for cancer-causing mutations may miss some important variations, as well as some of the structural variations, such as deletions, inversions, and translocations, that may inform us about a cancer's onset or biology. In addition, current technologies require large amounts of DNA and RNA in order to produce comprehensive data, so only larger (often, more advanced) tumors are suitable as subjects of study. Lastly, it's difficult to integrate information gained through these different analytic techniques.

MARC ROSENTHAL

With next-generation sequencing technologies, however, we can compare the genetic information in tumor tissue and normal tissue taken from the same person—a feat that was inconceivable until very recently *(see "Interpreting the Genome," p. 48)*. Our group used technology developed by Illumina to sequence the complete genomes of cancerous and normal tissue in a patient with acute myeloid leukemia; we identified 10 mutated genes that appear to play a role in this cancer. Since then, an improvement on this approach has been developed that makes it possible to discover structural variants. Next-generation sequencing also allows high-resolution comparisons of the "transcriptome"—a profile of the RNA molecules present at a particular moment in time—in healthy and cancerous cells. This approach can detect RNA expressed at extremely low levels, and it can reveal RNA messages that have been processed in different ways. In addition, these new technologies enable the characterization of microRNAs—short pieces of RNA (less than 25 DNA letters) that control gene expression—and other types of RNA that do not code for proteins. Finally, the methods can derive so much information from a single type of experiment that they require only a small amount of DNA and RNA.

Because cancer genomics is relatively new, it's led to only a few diagnostic tests so far. For example, some large clinics now screen tumor DNA from lung adenocarcinomas to determine whether the tumors will respond to tyrosine kinase inhibitors. The acceleration of cancer-related discoveries that will result from using next-generation sequencing will dramatically increase the potential for developing more such tests. Although these data provide just an initial step toward improving treatments and outcomes for cancer patients, it is a crucial one. TR

ELAINE MARDIS IS CODIRECTOR OF THE GENOME CENTER AT WASHINGTON UNIVERSITY SCHOOL OF MEDICINE IN ST. LOUIS.

COMPUTING

Multicore Programming

PAUL TYMA EXPLAINS THE NEED FOR LANGUAGES THAT TAKE FULL ADVANTAGE OF MULTICORE PROCESSING.

THE EVOLUTION of computer programming has been largely independent of actual computer evolution. Languages such as C++ have lived through many generations of computers, and although they've surely been influenced by changes in technology, most modifications of them have been attempts to meet the needs of people, not computers.

Computer evolution, however, is now headed down an entirely new path: instead of simply becoming faster, our computer processors are being conjoined to work together. That new computer architecture requires a serious evolution in computer programming. Without it, we can only scratch the surface of what multicore computing can really do *(see "Parallel Universe," p. 54)*.

It's a change that will not come easily. The last great shift in computer programming was object orientation. This didn't just represent a new language or syntax; it represented a new way of thinking about programming, a new way of visualizing programs even before the first line of code was written. Some programmers simply could not make the leap. Whether their minds were too stuck on procedural development or the concepts themselves were too abstract, they couldn't adjust what they knew.

Programming for multicore technology is again not just a fantastic leap in programming, but a leap in conceiving and understanding programs. Historically, programming could be described as giving instructions to a computer on how to act upon some public data; the easier it was to get to the data, the faster and easier coding would be. The principle is similar for multicore programming, except that you must consider that others may be acting on the data at the same time. Programmers must now take into account that someone else might be simultaneously sharing the data their code will work on.

One reason this problem has proved difficult is our insistence on shoehorning old languages into the new paradigm. Languages such as Java and C++ are being patched or updated to try to keep up, but programs written in them require careful coding when run on multicore chips. The good news is that new languages—built with the idea that shared data can and will change without notice—are better suited to this new paradigm. Part of their success lies in the fact that they are designed to keep data unshared until the programmer explicitly says otherwise.

With these new languages and programmers' development of new skills, the acceleration of computing power that we've almost come to take for granted will soon be back on track. TR

PAUL TYMA IS THE CTO OF HOME-ACCOUNT, AN ANALYTICS STARTUP FOCUSING ON THE MORTGAGE INDUSTRY. PREVIOUSLY HE WAS A SENIOR ENGINEER IN GOOGLE'S MULTICORE TEAM.

SPOTLIGHT ON INNOVATION

A TECHNOLOGY REVIEW CUSTOM SERIES

The Technology Review Custom Team takes a look at the technologies that are changing the ways in which we do business. The second article of four looks at the mobile industry, including technologies such as location-based services and translation software that continue to push the industry forward.

BEYOND THE IPHONE

In the past decade, cell phone use has exploded around the world: more than a billion mobile phones were sold in 2007 alone. Hundreds of new mobile applications have been launched to meet the demand for innovative new services, even as Web browsers have improved content delivery.

REACHING CALLERS

Mobile marketing holds great appeal, in large part because it offers the ability to carefully tailor the message and ensure that it reaches the right customer. According to Nielsen Mobile, nearly 77 million U.S. mobile users reported seeing some form of advertising on their phones.

The careful growth of the industry here in the United States has allowed members of the Mobile Marketing Association (MMA) to develop appropriate guidelines for obtaining consumer consent, explains Michael Becker, MMA board member and executive vice president for the marketing company iLoop. "You might go to usatoday.com and send a text message to a number to receive news alerts, or text Obama's site and receive content and news on what he's doing," Becker says.

It has proved difficult for many companies to translate their Web presence into a mobile one, due to different content abilities and the high cost of designing and implementing necessary changes. In November, Unity Mobile, based in St. Petersburg, FL, and the Czech Republic, unveiled a new service that allows companies of all sizes to seamlessly and affordably transform their Web content into a mobile-friendly format.

"The future of the Internet is being significantly shaped by mobility," says Daniel West, CEO. "We designed Unity Mobile to be the foundation for organizations to reach their potential in the mobile channel."

WHERE IN THE WORLD

Providing location-based services remains a challenge, according to Becker, because these features "are not interoperable across networks and are not yet standard, and not every phone supports these features."

This challenge has been taken up by Loc-Aid, based in Boca Raton, FL. The company is the first to develop what's known as location aggregation: determining the source and accuracy of the location information, and wrapping privacy protection into the package. Loc-Aid bundles this information, signs agreements with carriers, and sells the information to customers. "The Weather Channel could use it for their application, or mobile marketing could send alerts based on your location," says Isias Sudit, Loc-Aid's founder and CEO.

"Location until now has been handset specific," he continues, citing the iPhone and BlackBerry. "We don't care what handset you use." Loc-Aid recently deployed the first system in Canada and will soon be launching with three U.S. carriers."

CROSSING THE LANGUAGE BARRIER

"The mobile phone has probably been the most revolutionary device in the last decade for the emerging world," says Kent Lupberger of the World Bank's Global Information and Communication Technologies department.

China provides a strong example of mobile growth, as the country now has more than 50 percent penetration in terms of mobile use. Moka, an e-learning company based in West Palm Beach, FL, developed a highly accurate translation system for mobile phones that could facilitate potential international business opportunities. The system offers users in China the ability to have texts automatically translated from Chinese into English, and vice versa. "This is a powerful new way to communicate, where otherwise it would be very difficult to create and maintain relationships," says Michael Donahue, Moka's CEO.

China Mobile, the largest wireless carrier in the world, signed a contract with Moka in November. The company will soon unroll a similar service in the United States for English and Spanish speakers.

As the number of handheld devices has now overtaken that of computers in use, the field offers continual opportunities for innovation and growth.

Continues online:

Read the complete article, including a piece about mobile gaming, at www.technologyreview.com/spotlight.

INTERFACES

TOUCHING THE FUTURE

Next steps for touch screens

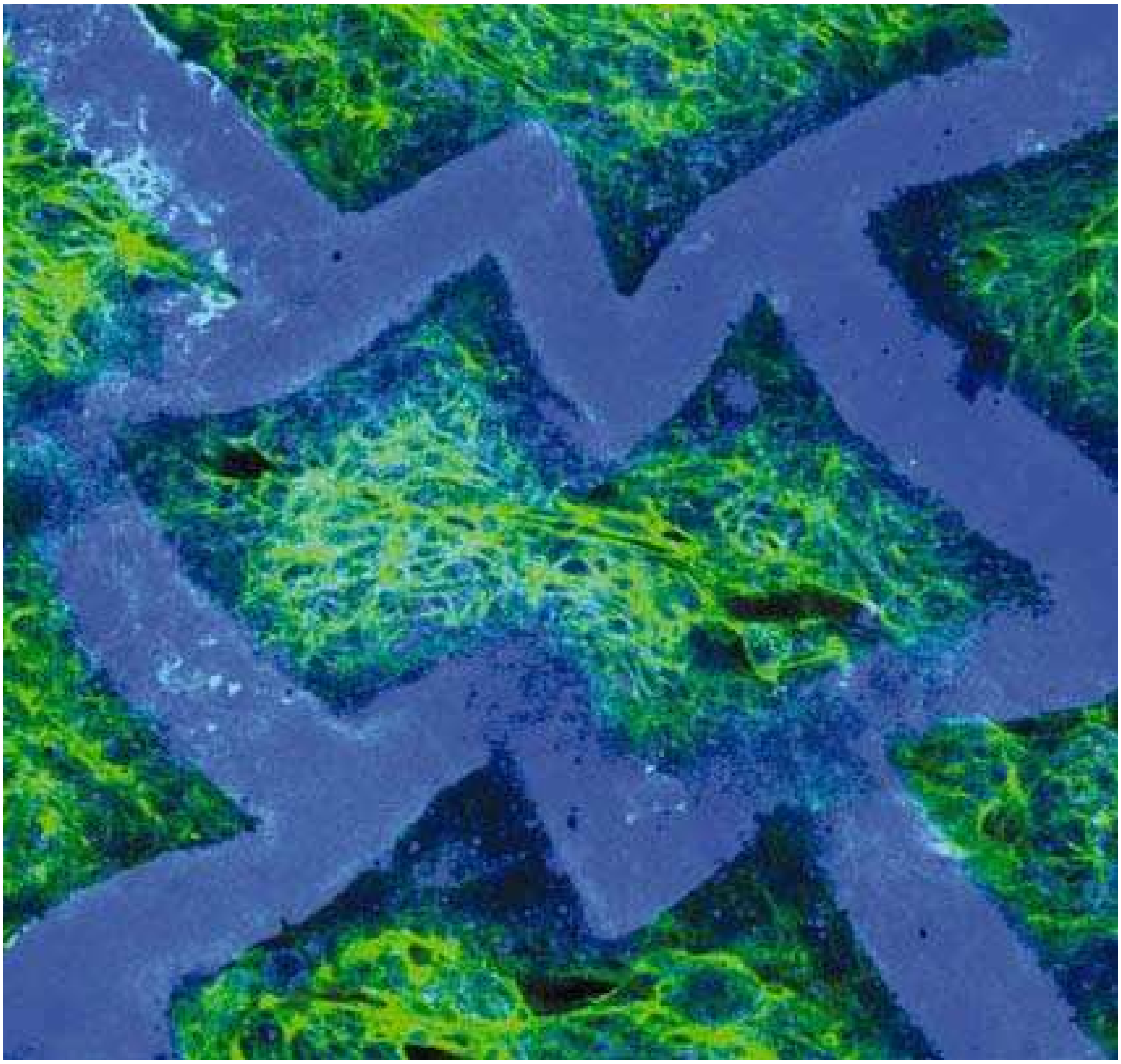
RESEARCH ON touch screens didn't end with the Apple iPhone. Microsoft's Patrick Baudisch, who's also a professor at Potsdam University in Germany, has developed a prototype display the size of a credit card, with a touch pad on the back *(right)*. A cursor indicates the position of the user's finger, but the tiny screen remains unobstructed.

At the opposite extreme, Jeff Han of Perceptive Pixel in New York City is using his large touch screens' pressure sensitivity to create new graphical interfaces. The screens made a splash during TV coverage of the 2008 election, as news analysts panned across maps by swiping the screens with their fingers. Light travels within an acrylic pane overlying the screens. Touching the pane scatters the light, indicating the point of contact and the pressure exerted. Han has developed software that lets users manipulate on-screen data in three dimensions rather than two, sliding virtual objects under each other by pressing down on them.

Three-dimensional manipulation is also the goal of a touch-screen table demonstrated by Yasuaki Kakehi of the Japan Science and Technology Agency and Takeshi Naemura of the University of Tokyo. The surface of the table diffuses light, displaying different scenes at different viewing angles. The researchers think the system could make video collaboration and conferencing more realistic. —*Kate Greene*

HASSO PLATTNER INSTITUTE

CLEAR VIEW The user's fingers don't obstruct the screen of this prototype device with a touch pad on the back.



SHAPING UP A polymer scaffold (purple) encourages heart cells grown on it (green) to align themselves in the same direction.

MATERIALS

PATCHING BROKEN HEARTS

Engineered tissue closely mimics the properties of the heart

HEART PATCHES grown from stem cells on biodegradable scaffolds could one day help treat heart attacks or congenital heart problems. But heart tissue is a mechanical marvel that's hard to mimic. Any substitute must be flexible enough to permit the contractions that drive blood through the body but strong enough to withstand them.

A new scaffold material developed by researchers at MIT approximates the mechanical, structural, and electrical properties of natural heart tissue. It's made of a biodegradable, rubber-band-like polymer carved with a laser into an accordionlike honeycomb pattern. The scaffold encourages cells grown on it to align themselves in the same direction, as they do in natural heart tissue. Because of the honeycomb pattern, the material is stiffer in the direction in which the cells are aligned than it is in the perpendicular direction, so it's both strong and flexible. When stimulated with electricity, muscle grown on the honeycomb scaffold beats just like heart tissue. So far, by seeding their scaffolds with heart cells from newborn rats, the researchers have made thin tissues that very closely mimic the properties of the heart's right ventricle.

In tissue engineering, it's unusual to tailor scaffold material to a particular tissue type; most researchers just rely on generic scaffolds. The MIT researchers hope that their approach will help advance work on other engineered tissues, such as blood vessels, tendons, and ligaments, whose mechanical properties are also direction dependent. They're building a library of honeycomb scaffolds with varying properties. –*Katherine Bourzac*

ENGELMAYR ET AL., *NATURE MATERIALS* 2008

PHOTOGRAPHY

Build Your Own Super-Camera

DIGITAL cameras and video cameras quickly become obsolete, but a new modular camera system will let photographers upgrade just about any part of their cameras rather than buying new ones. Aimed at professional photographers and filmmakers, the system uses interchangeable sensors, displays, hard drives, and other components that can be assembled in a variety of configurations. The complete cameras can produce both super-high-resolution still images and movies of a quality high enough for major studios.

Product: Red Digital Stills and Motion Camera
Cost: $2,500 to $53,000 for the digital sensor and processor, depending on their quality
Source: www.red.com
Company: Red Digital Cinema

PRINTERS

SOY TONER

ENVIRONMENTALLY friendly soy-based ink, used by newspapers for years, is now available for laser printers and fax machines. The toner in most printer cartridges is petroleum based: about two liters of oil yield one pound of toner powder, and volatile organic compounds are released in the process. Soy toner is made from a by-product of ordinary soybean harvesting, so it doesn't require the planting of any new crops, and no harmful chemicals are released during its manufacture.

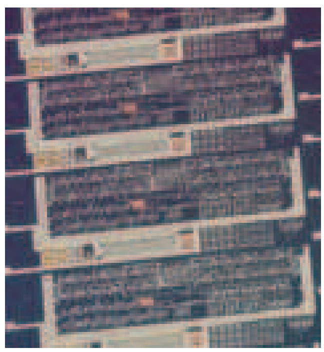
Product: SoyPrint toner cartridges **Cost:** $60 to $200, depending on printer type **Source:** thegreenoffice.com
Company: The Green Office

WIRELESS

CHEAP, PRINTED RFID

NEW RFID tags with circuitry deposited by simple printing technologies could finally make it cost effective to tag low-value products on retail shelves. The printing process eliminates the need for expensive optical lithography and reduces the consumption of energy and toxic materials, cutting costs: the tags cost less than half as much as existing ones. Mobile phones with built-in RFID scanners could let consumers access information about tagged products, or even pay for them without waiting in line.

Product: Kovio HF (13.56 MHz) printed integrated circuit **Cost:** Around 3 to 5 cents **Source:** www.kovio.com **Company:** Kovio

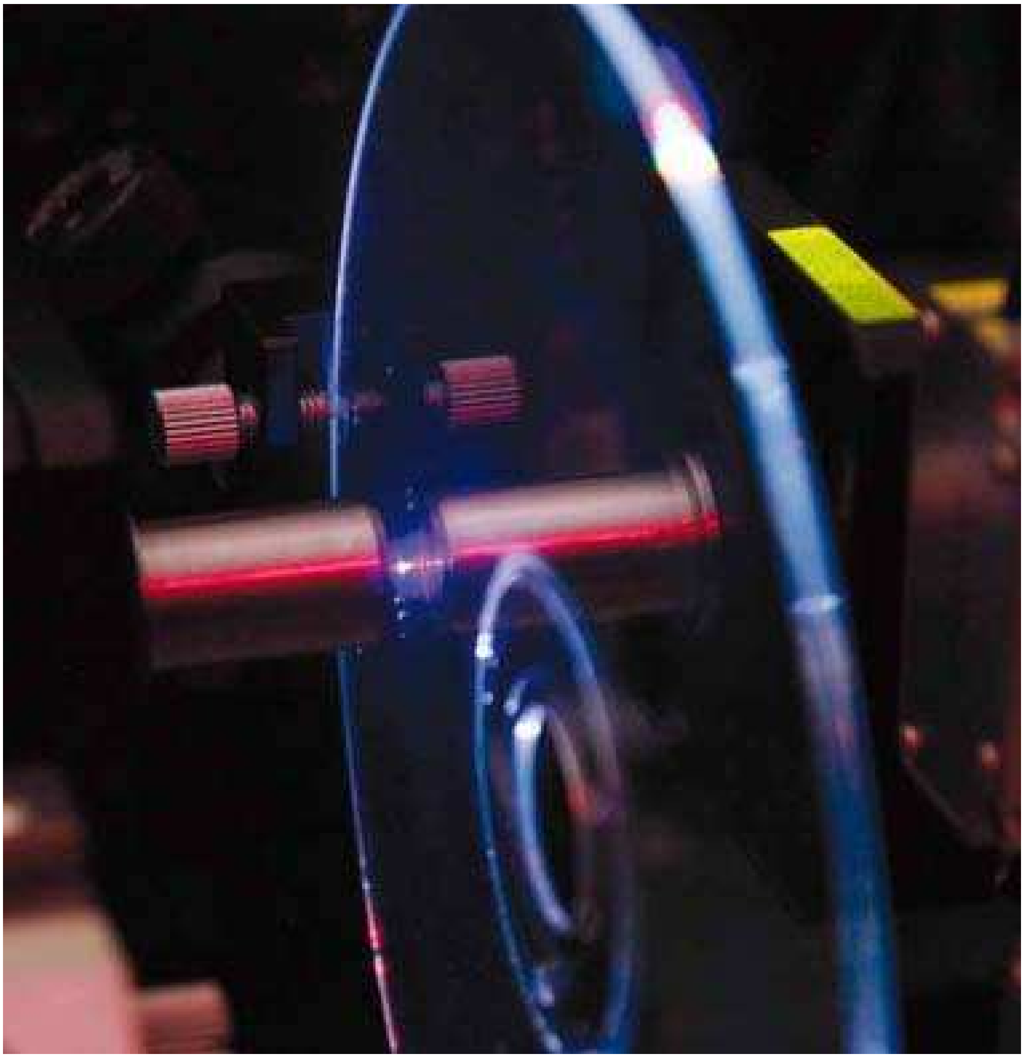


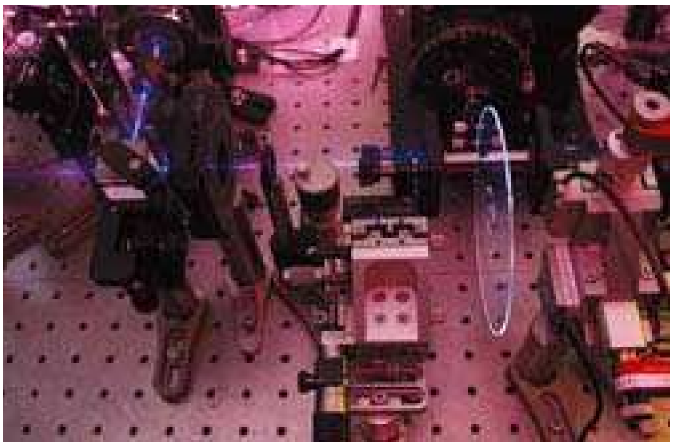
COURTESY OF RED (CAMERA); JOSHUA SCOTT (INK); COURTESY OF KOVIO (RFID)

STORAGE

BEYOND BLU-RAY

Holographic storage on the cheap





STACKABLE STORAGE
A hologram is produced by two beams of light that interfere with each other. In GE's prototype data storage system, the beams enter a disc from opposite sides (top). The experimental setup (bottom) includes a beam splitter (cube at left) that bounces one of the beams off of a mirror (not shown) to ensure that it travels the same distance as the other beam before striking the disc.

COURTESY OF GENERAL ELECTRIC

A CONVENTIONAL DVD stores data only on its surface. But holographic storage encodes data as three-dimensional patterns embedded inside a disc, vastly expanding its storage capacity. A long-awaited holographic drive from InPhase of Longmont, CO, is due out late this year; geared to Hollywood studios and large archives, it will cost $18,000. But a few companies, such as General Electric and Sony, are working on holographic storage systems that could be more compatible with existing technologies.

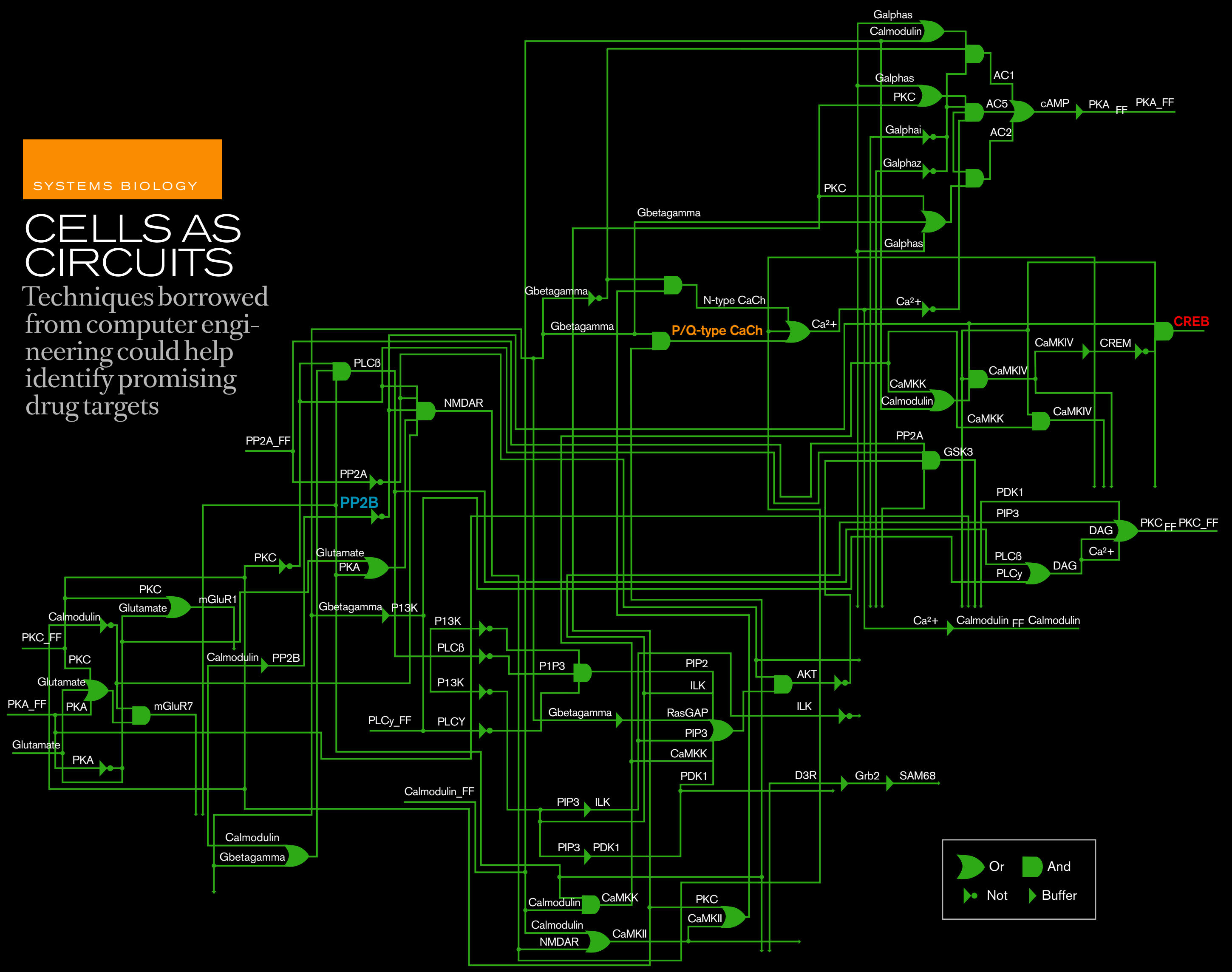
InPhase's drive stores information in big blasts, 1.4 million bits at a time. That makes data retrieval extremely fast, but it also requires complicated and costly optics. A prototype system from GE, on the other hand, stores information a bit at a time—just like today's media. That means that GE's holographic discs could be played on modified Blu-ray players, which could potentially handle old DVDs and CDs, as well.

In the GE technology, the holographic bits—each measuring 0.3 by 5 micrometers—are arrayed in a plane, with dozens of planes layered throughout the disc. Initial versions of the disc will hold 300 gigabytes of data—about six times as much as a Blu-ray disc—and might reach market by 2012. Brian Lawrence, manager of GE's Optical Polymer Lab, says that the technology should ultimately let a disc the size of a DVD store a terabyte of data. GE faces plenty of competition, however. Besides InPhase and Sony, other companies working on holographic storage include Daewoo and Maxell. *—David Talbot*

SYSTEMS BIOLOGY

CELLS AS CIRCUITS

Techniques borrowed from computer engineering could help identify promising drug targets



THE MAP of the human genome was expected to spark a revolution in drug discovery. But cells' behavior is determined by the interactions of hundreds of different proteins in what are known as signaling pathways, and figuring out which interactions go awry in disease has proved much harder than people thought.

Now, a study led by scientists affiliated with the New Jersey Institute of Technology (NJIT) has used circuit analysis to identify the molecules that play the biggest roles in cells' signaling pathways. The researchers believe that their work can save drug researchers time and money by identifying promising drug targets.

The diagram above represents only *half* of a pathway that regulates the production of a molecule called CREB *(red)*, which is involved in memory formation. The pathway is represented as a set of logic gates, the basic elements of digital circuits. An OR gate, for example, produces an output if it receives either of its inputs: here, that means that either of two molecules regulates the production of the next molecule in the pathway. Though each step in the pathway has been well studied in biology labs, the diagram provides a quantitative purchase on the network as a whole.

One molecule in this network, PP2B *(blue)*, is being investigated as a target for schizophrenia drugs. But the researchers' analysis shows that PP2B is less important to CREB regulation than P/Q-type calcium channels *(orange)*. PP2B plays a role in many other pathways, so targeting it could have unfortunate side effects. Calcium channels are the target of drugs already approved for other disorders, so they may also be a safer target for schizophrenia drugs.

The researchers applied their approach to three different signaling pathways, and their predictions agreed with experimental results. Effat Emamian, who led the research, has founded a company that markets signaling-pathway analyses to drug companies. *—Larry Hardesty*

SOURCE: EFFAT EMAMIAN AND ALI ABDI

STARTUPS

RECESSION-RESISTANT MEDICINE

Novel medical treatments thrive as investors grow cautious

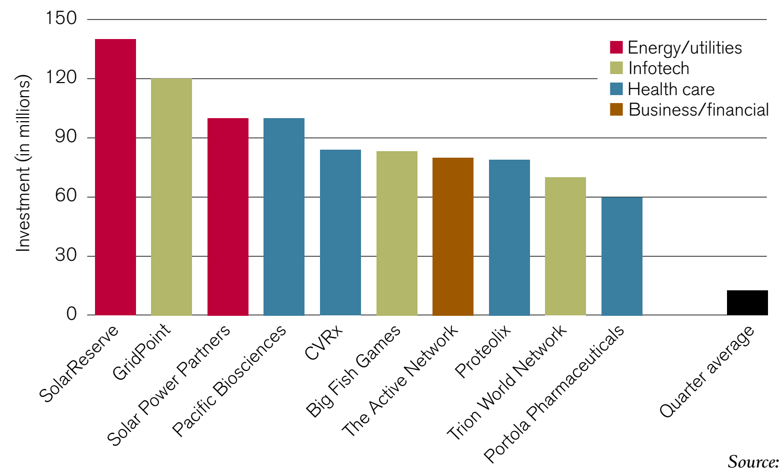
IN THE THIRD quarter of 2008, the first tremors of the financial crisis had been felt, and the number of venture deals in the U.S. fell to its lowest total since early 2005. According to Dow Jones's VentureWire, which tracks venture investment, information technology companies fared particularly badly, with their lowest deal total in more than 10 years.

But for the quarter, total dollars invested stayed fairly steady, off only about 1 percent from each of the first two quarters. So some companies were still getting big paydays. Of the 10 companies with the biggest third-quarter deals, the plurality—four—were in the health-care sector. One of those companies, Pacific Biosciences, builds genome-sequencing machines and figures prominently in Emily Singer's "Interpreting the Genome," on page 48. The other three are testing promising new therapies for some of the most common medical conditions.

—Larry Hardesty

HEAD OF THE CLASS

Biggest deals, third quarter of 2008



Source: VentureWire

CVRx

Between 25 and 33 percent of hypertension patients can't control their condition with medication. But the body has its own mechanisms for bringing blood pressure down, which are triggered by nerve cells in the carotid artery that respond to pressure. CVRx has found a way to treat severe, drug-resistant hypertension by stimulating those nerves electrically. A device the size of an iPod Nano is implanted in the patient's chest, with electrical leads snaking up to the carotid artery. The device is now in phase III clinical trials in the U.S. and Europe.

Product: Arterial stimulation to control hypertension
CEO: Nadim Yared
Location: Minneapolis, MN
Funders: New Enterprise Associates, Johnson and Johnson Development Corporation, others
Funding: $209 million
URL: cvrx.com

PROTEOLIX

Cells clean up unneeded proteins by shipping them to a structure called the proteasome, which chops them up. If the proteasome can't do its job, the cell eventually dies. By targeting a specific component of the structure, Proteolix has developed a proteasome inhibitor that is particularly deadly to cancer cells. In the right doses, it kills cancer with little damage to healthy tissue. A variation on the molecule targets the proteasomes in immune cells (which differ from those in normal cells), disrupting biochemical pathways that cause autoimmune disorders.

Product: Drugs that target the proteasome
CEO: Susan Molineaux
Location: South San Francisco, CA
Funders: Nomura Phase4 Ventures, Advanced Technology Ventures, Delphi Ventures, others
Funding: $143 million
URL: proteolix.com

PORTOLA

Portola's drugs treat blood clots, which form when collagen-containing plaques on artery walls rupture. Collagen is one of the supportive tissues in blood vessels, so the body reads its sudden appearance as indication of a wound, which it sends blood-clotting agents to repair. Portola designed an imaging system that lets researchers observe blood clots forming in collagen-lined capillary tubes. The simulations led to a drug candidate that's in clinical trials as a competitor to Plavix, the world's second-best-selling drug.

Product: Drugs for treating blood clots
CEO: Charles Homcy
Location: South San Francisco, CA
Funders: Advanced Technology Ventures, Prospect Venture Partners, Sutter Hill Ventures, MPM Capital, others
Funding: $218 million
URL: portola.com

TO MARKET

SENSORS

CAFFEINE DETECTOR

SOMEWHERE between 20 and 30 percent of supposedly decaffeinated coffee and tea is actually fairly high in caffeine, but a new test kit can help people tell the difference. A strip of paper soaks up fluid from a sample, and antibodies in the strip produce colored lines if the sample contains caffeine. The antibodies were designed by the test's manufacturer, Silver Lake Research, which also has antibody tests for contaminants in food sources and water.

Product: D+caf Test Strip **Cost:** $9.95 for a package of 20 strips
Source: discovertesting.com **Company:** Silver Lake Research

JOSHUA SCOTT

PHOTOGRAPHY

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COURTESY OF RED (CAMERA); JOSHUA SCOTT (INK); COURTESY OF KOVIO (RFID)

INTERFACES

WEARABLE MEDIA CENTER

A NEW headset from Nikon, released in Japan, is a completely self-contained entertainment center. Media-playback software and up to eight gigabytes of memory are built in, and with two AA batteries installed, the headset weighs less than a pound. According to Nikon, the adjustable eyepiece simulates a 50-inch TV screen viewed from about 10 feet away. The key to the picture quality is a light-diffraction grating that emerged from the company's research on camera lens design. Data can be loaded onto the headset through either a USB cable or a Wi-Fi connection.

Product: Media Port UP300 and UP300x **Cost:** About $650 to $750, depending on storage capacity **Source:** www.nikon.com **Company:** Nikon

E-BOOKS

LARGE-SCREEN E-READER

A NEW e-reader from Plastic Logic has a much bigger screen than the Sony Reader or the Amazon Kindle—8.5 by 11 inches. The screen's backplane is plastic instead of glass, with circuitry deposited using Plastic Logic's proprietary process, so it doesn't require much protection: the device is only about a quarter-inch thick. The screen itself is plastic, too, which makes it extremely durable, and it's touch sensitive: the user turns the page by swiping the screen with a finger.

Product: Plastic Logic Reader **Cost:** Competitive with existing readers, which range from $350 to $850 **Source:** www.plasticlogic.com **Company:** Plastic Logic

COURTESY OF PLASTIC LOGIC (READER); COURTESY OF NIKON (MEDIA)

SOFTWARE

Voice Googling

THE LATEST version of Google's search application for the iPhone lets users enter search terms simply by speaking them. Voice search poses a big challenge: where an airline reservation system, say, can make do with a limited vocabulary—dates, destinations, and the like—search is totally unconstrained. But Google has taken advantage of its wealth of data on how people search: if the application has trouble interpreting a word, it can consult tables of terms that are frequently used together.

Product: Google Mobile App **Cost:** Free **Source:** www.google.com/mobile/apple/app.html **Company:** Google

AUTOMOTIVE

ELECTRIC MINI

BMW stole a march on some more ballyhooed electric-car programs by releasing an electric version of its Mini at the end of 2008. Where most of its competitors are engineering electric cars from scratch, the German automaker was able to adapt an existing electric drive system from California's AC Propulsion to fit the Mini's chassis. Five hundred of the cars are available for lease for a year, during which BMW will collect data about their use in preparation for a larger rollout.

Product: Mini E
Cost: $850 a month for a one-year lease, insurance included
Source: www.miniusa.com/minie-usa
Company: BMW

ENERGY

ROOFTOP WIND POWER

HOMEOWNERS can knock 20 to 40 percent off their electricity bills with a new wind turbine that can be mounted directly on a building. The seven-foot-wide plastic turbine has a ring around its rotors that diffuses noise and limits vibration; the company claims that the turbine is no louder than a whisper. In windy locations, its power output should be about 2,000 kilowatt-hours a year.

Product: Swift wind turbine **Cost:** $10,000 installed and connected to the grid **Source:** swiftwindturbine.com
Company: Cascade Engineering

PSYCHIATRY

Magnetic Depression Treatment

FOR THE 30 percent of clinically depressed people who don't respond to medication, the U.S. Food and Drug Administration recently approved a new, noninvasive treatment option. With NeuroStar TMS, a wand held over the head delivers highly focused magnetic pulses to a part of the brain that's been linked to depression. A typical course of treatment would involve 40-minute sessions at a psychiatrist's office five times a week for four to six weeks. In two clinical trials, roughly half of patients said that their symptoms were reduced by at least 50 percent.

Product: NeuroStar TMS Therapy system **Cost:** Approximately $6,000 for a course of 20 to 30 sessions, depending on the provider **Source:** www.neurostartms.com **Company:** Neuronetics

COURTESY OF BMW (MINI); COURTESY OF CASCADE ENGINEERING (WIND); COURTESY OF NEURONETICS (DEPRESSION)

Technology Review's Career Resources

Do you want to take the next step toward professional growth? In each issue, Career Resources brings you success stories from executives who continued their education, essential advice from experts on how to achieve your career goals, and a directory of programs designed specifically for the working professional. **www.technologyreview.com/careerresources/**.

Career Growth Profile

Arvind Salian

Age: 40

Job Title: Automotive New Production Introduction PE Manager

Employer: Freescale Semiconductor

Graduate Programs: MBA, Arizona State University, 2006; PhD, electrical engineering, University of Michigan, 2001 ; MS, electrical engineering, University of Arkansas, 1993; BS, engineering, Karnatak University, India, 1990.

Growing up in Mumbai, India, Arvind Salian epitomized "happy go lucky." The youngest of four children in a middle-class family, Salian studied just enough to make decent grades, but he much preferred being outdoors, playing sports with the neighborhood kids. His mother and sisters were constantly on his case, making sure he did his homework.

But at age 20, everything changed. Salian suffered a serious injury while playing soccer. It left him bedridden for several months, and the former athlete had to learn how to walk again.

"The feeling of helplessness and not having achieved anything of significance in my life in spite of having been given every opportunity by my family forced me to look at things differently," he says.

Upon his recovery, Salian enrolled at the Gogte Institute of Technology at Karnatak University in India and earned his bachelor's degree in engineering. Then, at age 23, he made a solo journey to the United States to continue his pursuit of higher education. Today, with two master's degrees, a PhD, and five patents under his belt, this PE manager at Freescale Semiconductor has found success on an entirely new playing field.

In Freescale's Sensor and Actuators Solutions Division, Salian manages a 12-member product engineering team to meet new product introduction (NPI) deliverables targeted for auto markets. It's a job that requires an in-depth understanding of what makes a product commercially successful, from its design and function to its pricing and marketability.

Salian's supervisor, Mike Cheperak, puts it this way: "Automotive NPI is largely about systems on chip (SOC) and system solutions in general. As the component manufacturers add more content to our products, the value of these features must be understood not only from an applications perspective—to design, validate, and test—but also from an engineering perspective. Arvind's input and understanding of the business models have helped the marketing teams to accurately price and promote products. Additionally, his understanding of our customers' road maps and strategies has improved our ability to add value to our new products."

To learn more about Arvind's success at Freescale and his decision to continue his education, go to **www.technologyreview.com/careerresources/**.

Program Directory

Q&A

GILBERT METCALF

The case for a carbon tax

Many economists argue that painful though it might be to consumers, the best way to address climate change is to put a "price" on carbon dioxide and other carbon-based emissions, thereby making fossil fuels more expensive and alternative energy sources more competitive.

The European Union established a trading program for carbon emissions in 2005. In the United States, a proposal for a similar system is at the center of the new administration's energy policy. Under such programs, a regulatory authority sets a cap on total carbon emissions, and tradable emissions allowances are issued or auctioned off to industries. But many economists advocate a far simpler approach: a carbon tax levied directly on the production of fossil fuels.

Over the last several years, Gilbert Metcalf, an economist at Tufts University, has calculated the costs and consequences of such a policy. He explains to *Technology Review* editor David Rotman why a carbon tax is a good idea.

_TR_: How much revenue would a carbon tax raise in the U.S.? Who would get the money?

Metcalf: For an initial tax of $15 per ton of carbon dioxide, I estimate that the tax would raise about $85 billion annually. The U.S. Treasury would get the money. But your real question is, What does the Treasury do with the money? I have proposed creating a tax credit in the personal income tax. That ensures that we don't raise the overall tax burden during this recession and that we don't disproportionately burden low-income households.

Why a carbon tax, rather than a cap-and-trade program?

As businesses are planning long-lived investments, power plants that last 50, 60 years or longer, they need to know what price they are going to face to make these plants competitive. With a tax, we know what that price is. It's the tax rate. With cap-and-trade, we have much less certainty about what the price will be. For example, we're seeing carbon prices falling [in the E.U.] because the demand for energy is falling as the economy slows down.

Beyond allowing for a more predictable price, why is a carbon tax better than a cap-and-trade scheme?

It's much simpler. From both an efficiency and an administrative perspective, a carbon tax is a better approach. I think there is a clear consensus on that among economists.

Would I have to pay a carbon tax on my electric bill or at the gas pump?

No. The best way to do a carbon tax would be to tax coal as it comes out of the ground. You can levy the tax where it is most convenient: the coal mine. For oil, at the refineries. It's pretty easy to catch all the fossil fuels with a small number of taxpayers. Administratively, it is very easy.

Nevertheless, the impact of the tax will, of course, reach the consumer.

Yes.

Given the woeful state of the economy, how politically feasible is such a new tax?

The political momentum clearly favors cap-and-trade. The game in Washington has been to design a cap-and-trade system that acts as much as possible like a carbon tax without being a tax.

Is the cap-and-trade scheme really working in the E.U.?

We're starting to get some sense. I think it will not be effective at achieving the targets. It is a partial system. It is only including the electric-utility sector and some energy-intensive industry. The transport sector is not in the system at all. There are certainly many lessons that we can learn from the E.U. approach, but the most important lesson may be how not to design a carbon-trading system.

With the price of oil so low, does a carbon tax's effect on innovation get lost?

It does. Most of the proposals putting an initial price on carbon emissions only add about 25 to 40 cents to the price of a gallon of gas. The real action will be in the coal sector. It has a huge impact there. The transport sector is very important—something like 40 percent of our carbon emissions come from the transport sector—but that is not the cheapest place to get our initial emission reductions. The cheapest will be the electric-utility sector and industry.

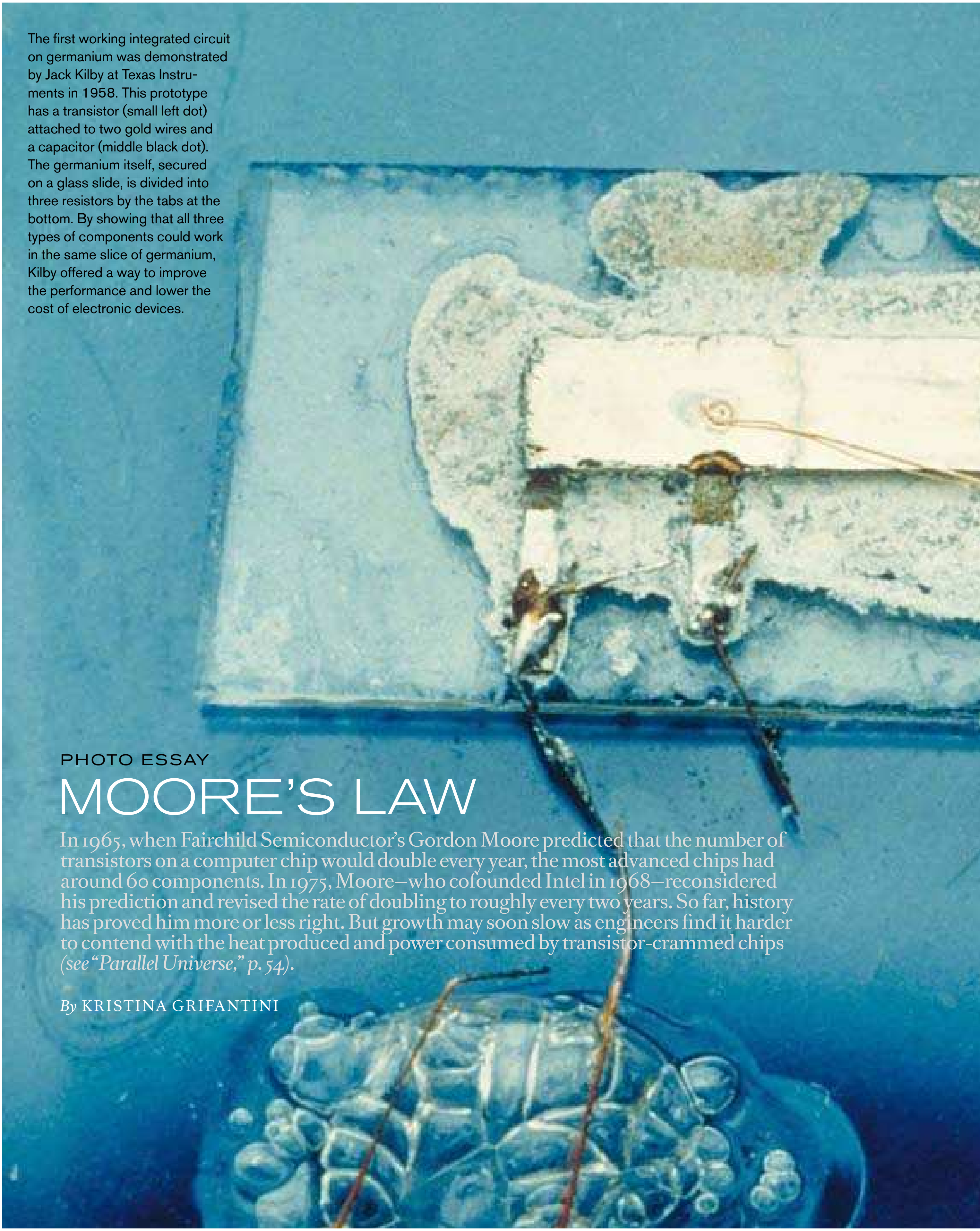
How much will a carbon tax add to the cost of electricity?

A $20 tax per ton of carbon dioxide adds about 15 percent to the cost of electricity. For coal-fired electricity it will be a lot more. It will more than double the price of coal—about a 40 percent increase in the price of coal-generated electricity.

Is the current economic recession affecting this debate?

The interesting fallout from the economic crisis is that there has been this love affair with the cap-and-trade approach: we create these markets, we create these assets and let trading happen. Well, I think some of the bloom is off the rose in creating these kinds of [financial] instruments. I don't know what it will mean for the relative attractiveness of a carbon tax versus a permit approach, but I think that it could make the tax that much more politically attractive. TR

Photograph by CHRISTOPHER CHURCHILL



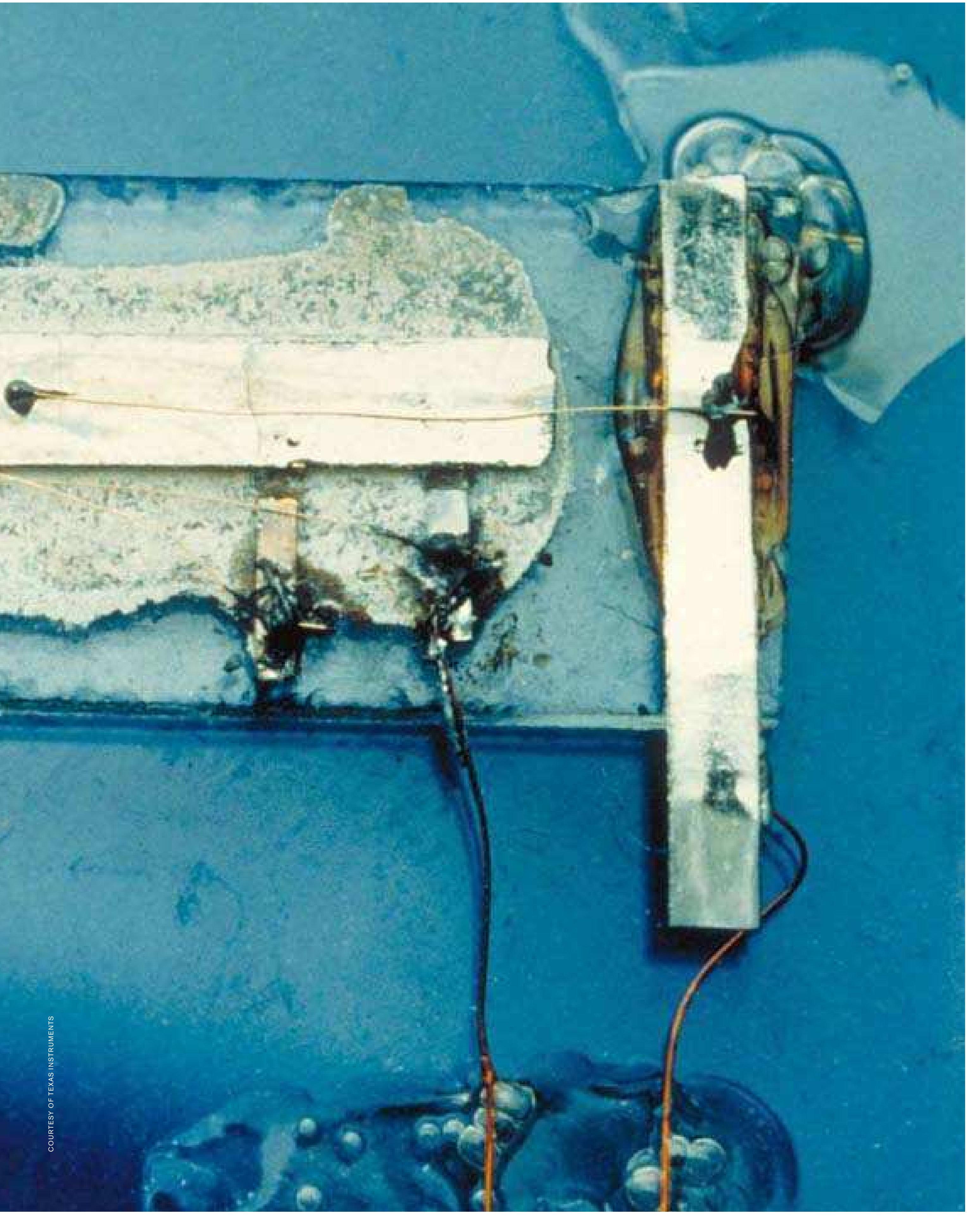
The first working integrated circuit on germanium was demonstrated by Jack Kilby at Texas Instruments in 1958. This prototype has a transistor (small left dot) attached to two gold wires and a capacitor (middle black dot). The germanium itself, secured on a glass slide, is divided into three resistors by the tabs at the bottom. By showing that all three types of components could work in the same slice of germanium, Kilby offered a way to improve the performance and lower the cost of electronic devices.

PHOTO ESSAY

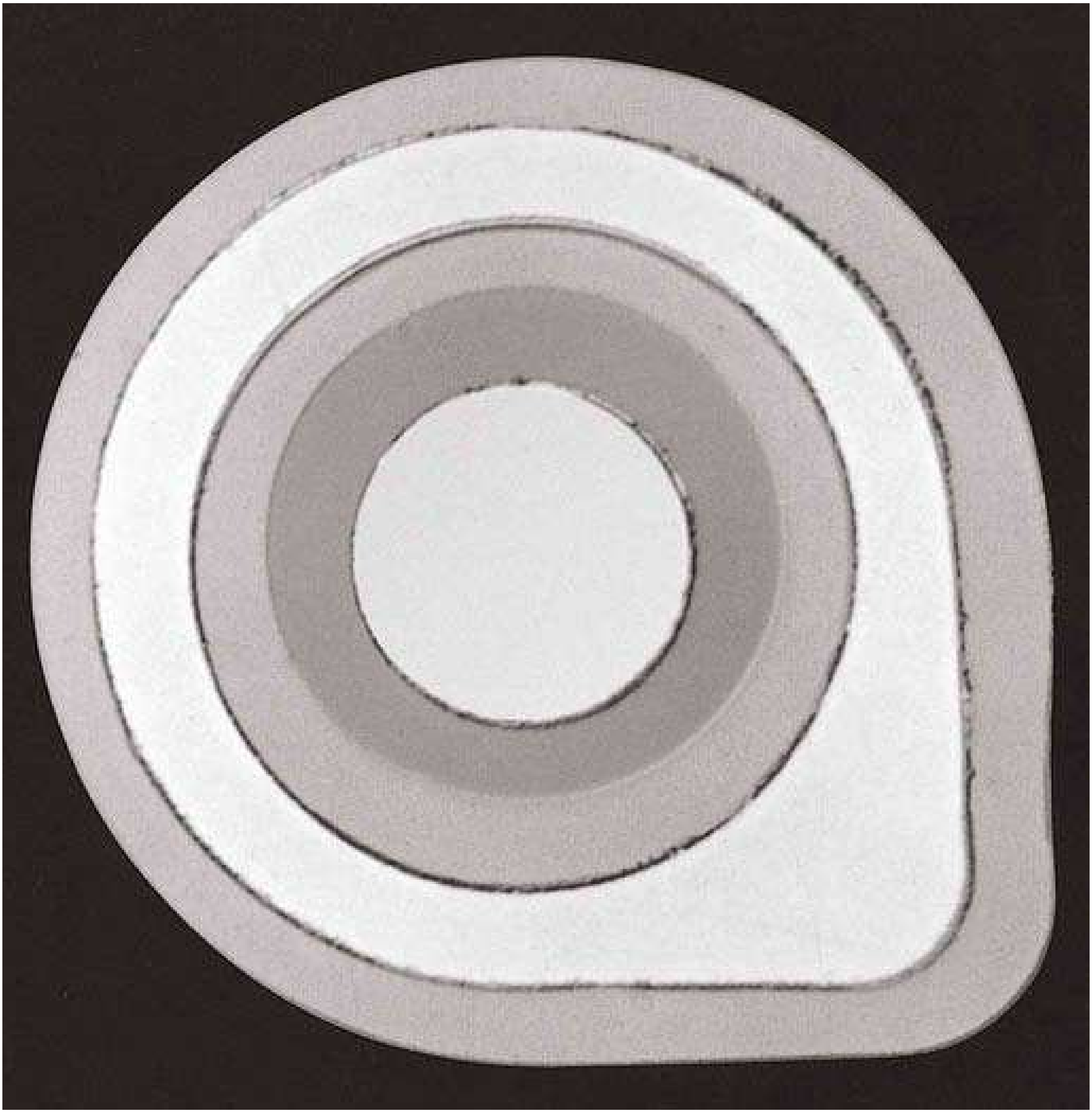
MOORE'S LAW

In 1965, when Fairchild Semiconductor's Gordon Moore predicted that the number of transistors on a computer chip would double every year, the most advanced chips had around 60 components. In 1975, Moore—who cofounded Intel in 1968—reconsidered his prediction and revised the rate of doubling to roughly every two years. So far, history has proved him more or less right. But growth may soon slow as engineers find it harder to contend with the heat produced and power consumed by transistor-crammed chips *(see "Parallel Universe," p. 54)*.

By KRISTINA GRIFANTINI

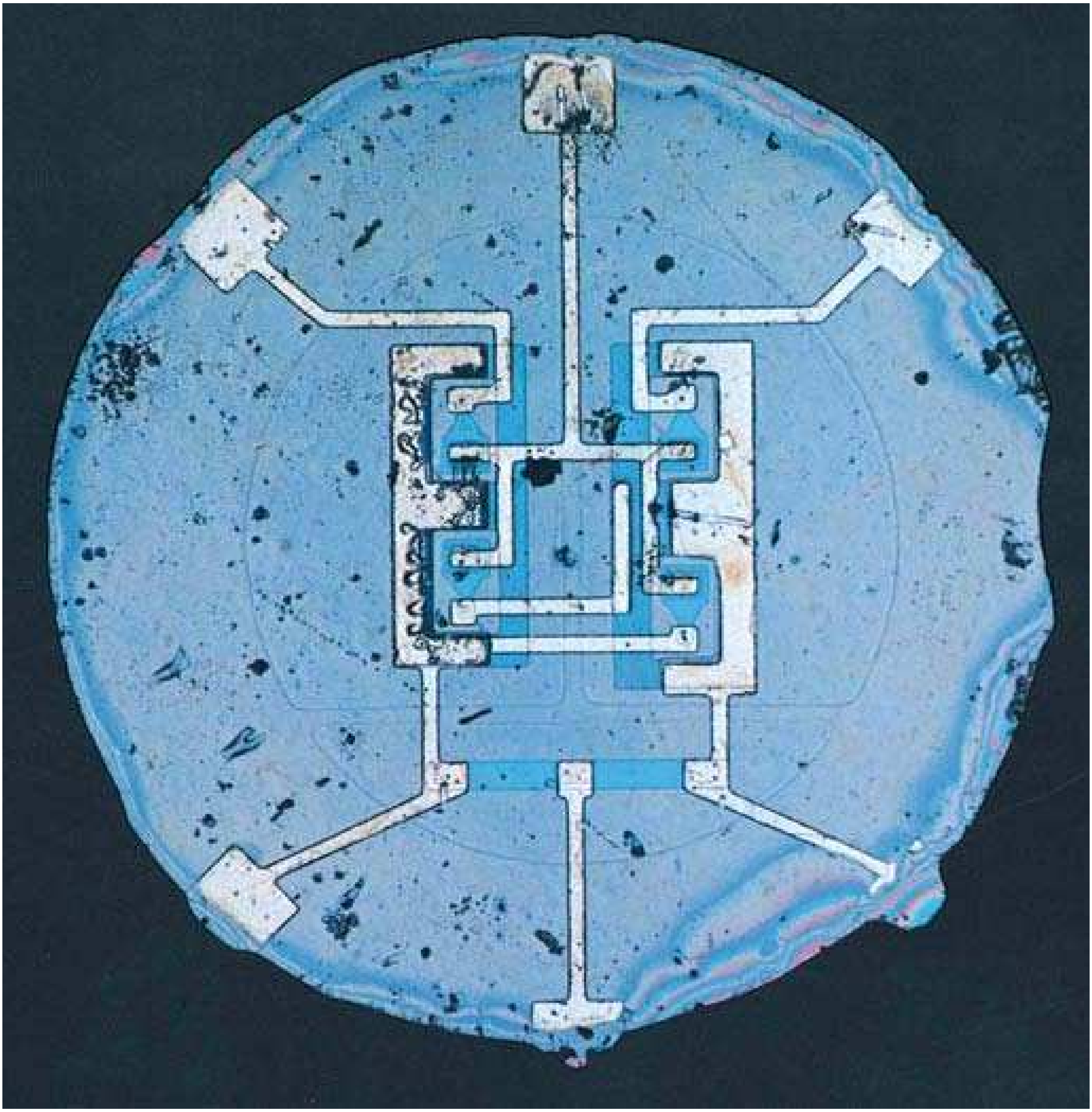


COURTESY OF TEXAS INSTRUMENTS



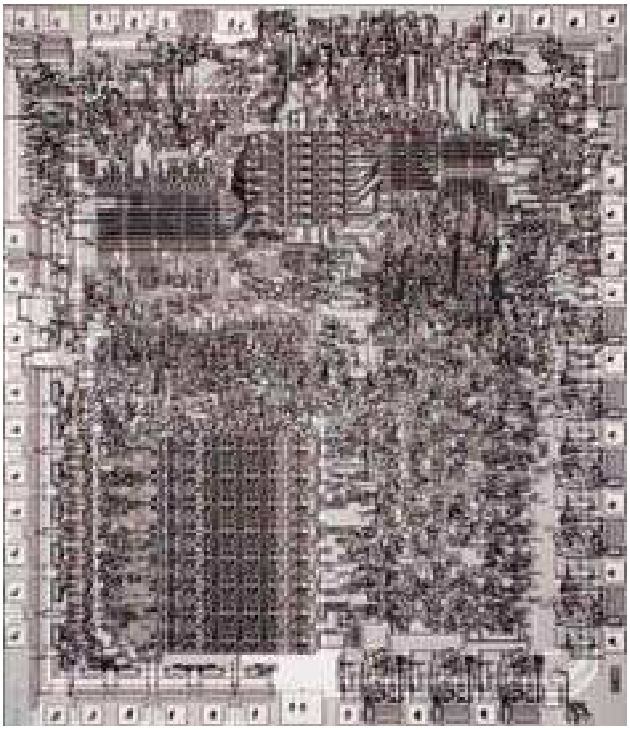
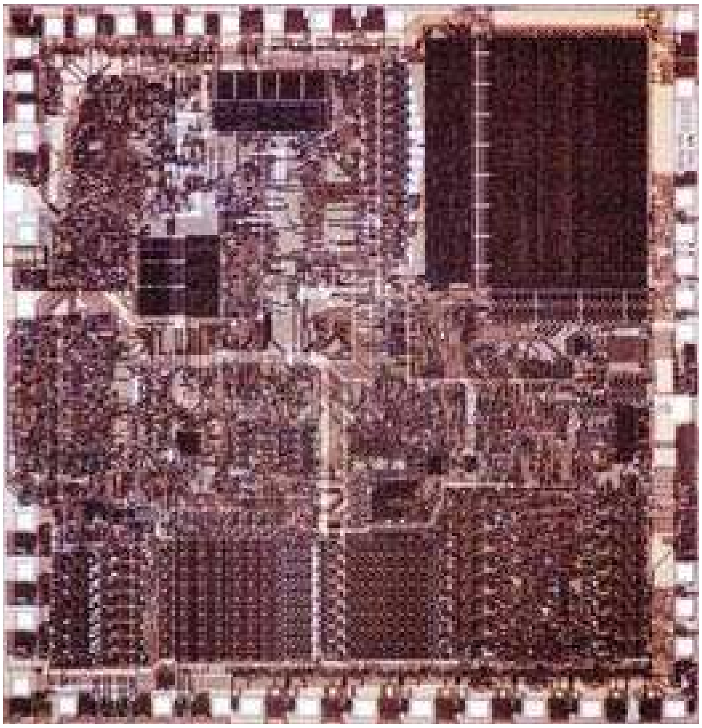
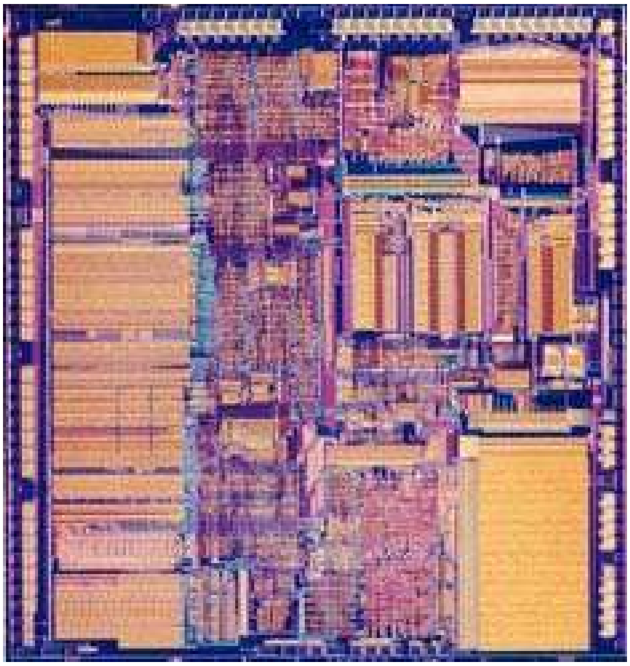
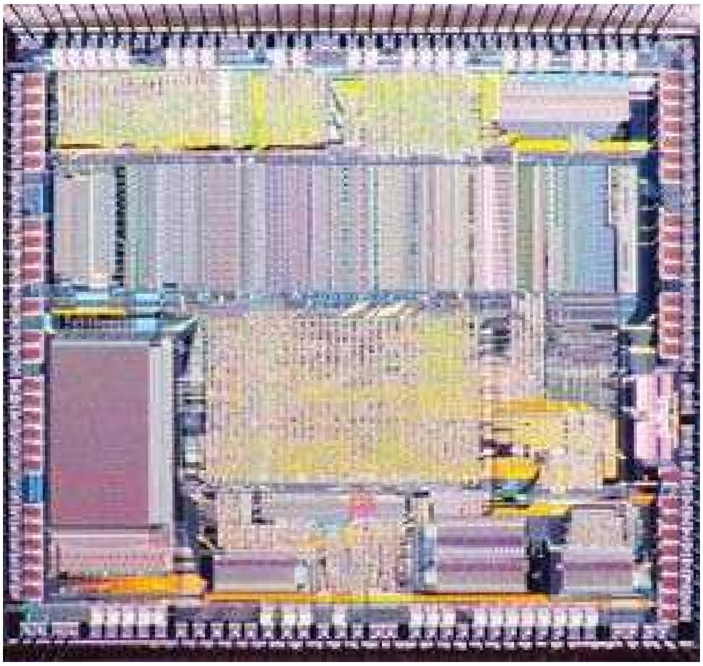
Jean Hoerni, a cofounder of Fairchild Semiconductor, invented the first planar, or flat, transistor in 1959. His novel manufacturing approach was to directly imprint semiconducting and insulating channels onto a silicon wafer. The process left intact a protective layer of silicon dioxide that formed naturally on top of the wafer and prevented contamination. The result was the best-performing transistor of its time.

COURTESY OF FAIRCHILD SEMICONDUCTOR



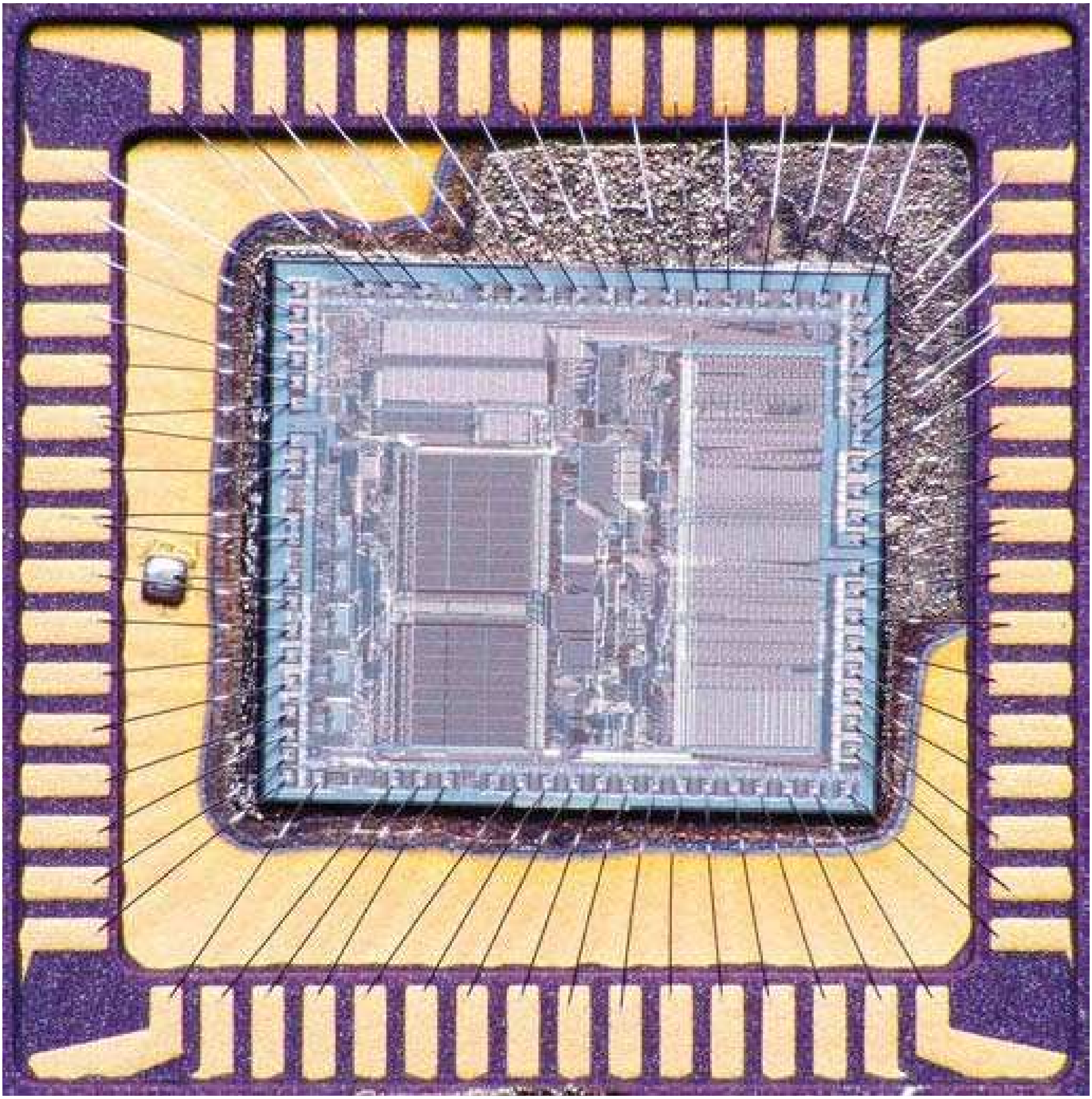
Robert Noyce—another Fairchild Semiconductor cofounder, who later cofounded Intel—saw a way to use Hoerni's process to combine multiple electronic components, including transistors, on a single piece of silicon. Announced in 1961, this resistor-transistor logic chip was one of the first commercial integrated circuits. It has four transistors (quadrants in the middle). The white lines are metal traces, which connect the transistors to the two resistors below (horizontal blue bar) . The Apollo Guidance Computer used the chip.

COURTESY OF FAIRCHILD SEMICONDUCTOR

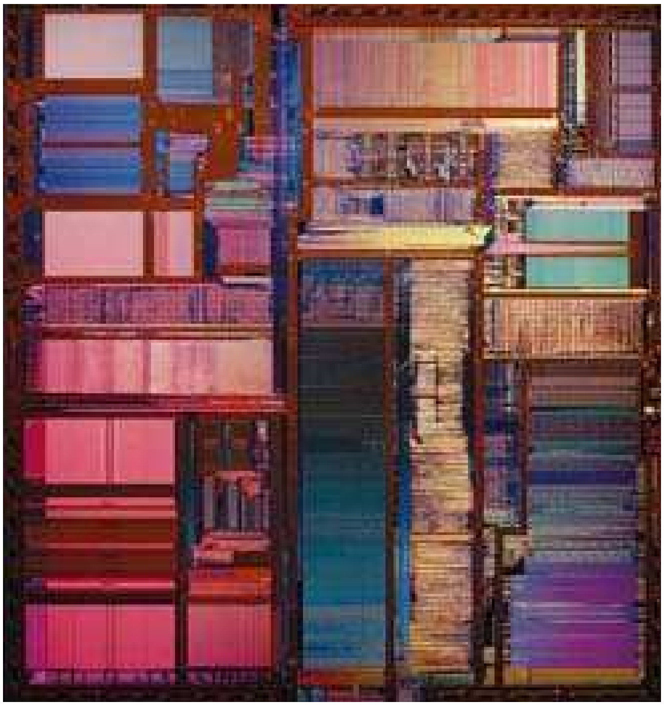
In 1974, Intel introduced the 8080 (top left). With roughly 5,000 transistors, it was the heart of the Altair personal computer. Four years later, Intel's 8086 chip (top right), containing 29,000 transistors, established the x86 architecture that still predominates among today's chips. Intel's 386 (bottom left), released in 1985, had 275,000 transistors and allowed a computer to work on multiple applications at the same time. (Its successor, the 486, was Intel's first chip with a data cache, which stored a subset of memory onboard for faster processing.) In 1991, AMD released its own 386 microprocessor, with approximately 200,000 transistors (bottom right), helping bring competition to the industry.

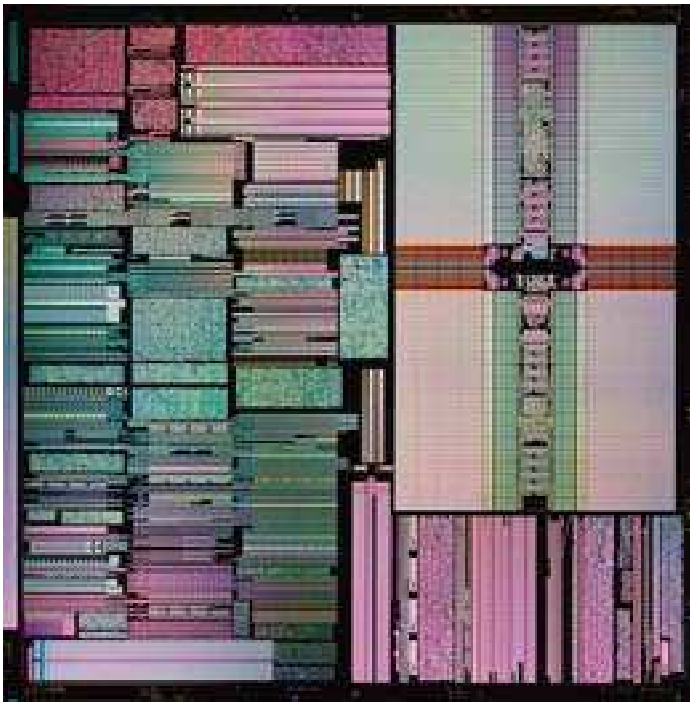
COURTESY OF INTEL, WILLIAM BLAKE



Motorola's 68000 microprocessor, introduced in 1979, had 68,000 transistors and powered the Macintosh 128K computer. Chips have several layers; shown here is the layer of wires that link transistors (central blue square). Larger wires around the chip connect it to the surrounding integrated-circuit package. The photographer teased out the colors in this chip by adjusting the lighting angle. A chip reflects and diffracts different colors of light depending on the width and spacing of its wires.

COURTESY OF WILLIAM BLAKE

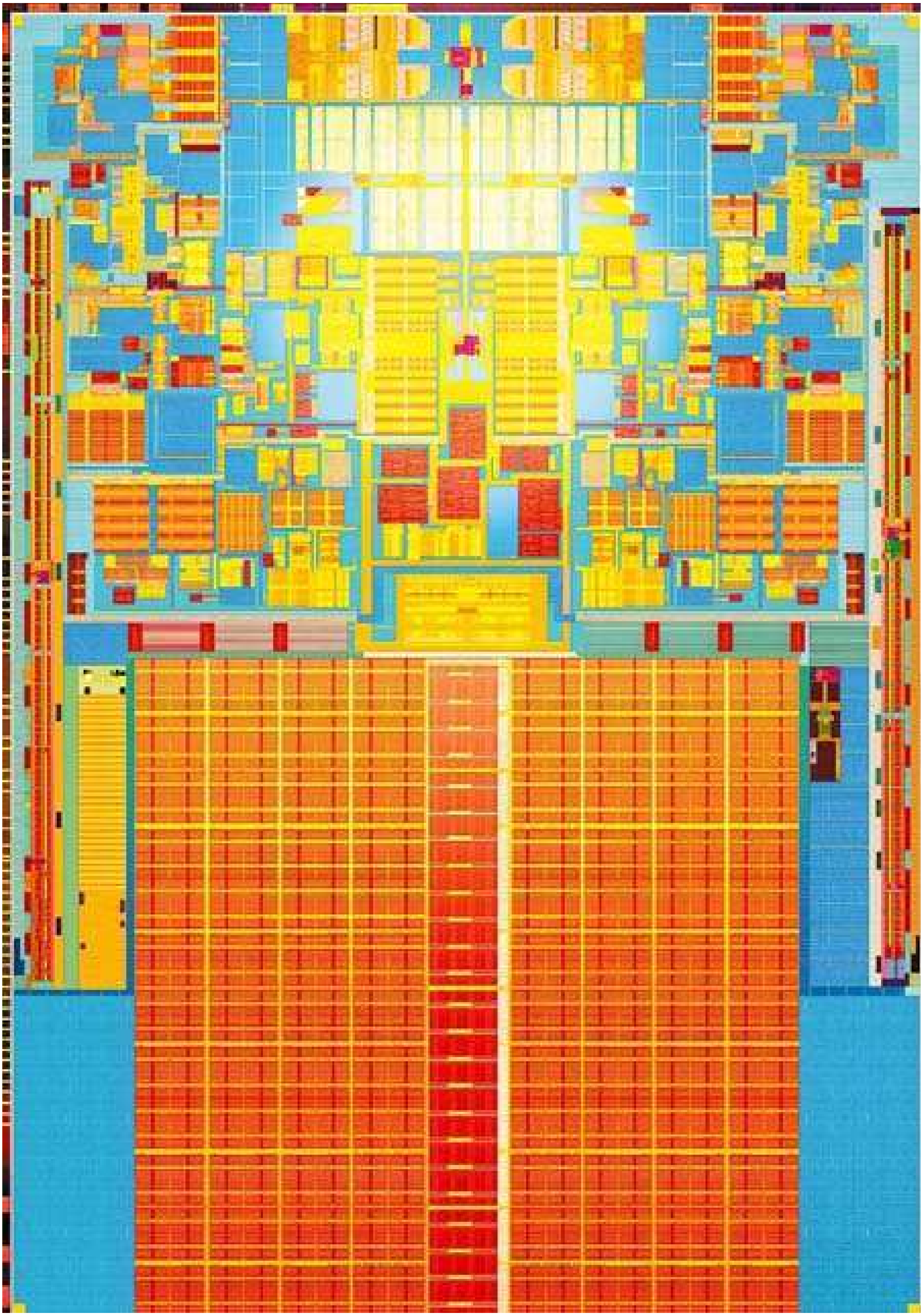




The Pentium processor (upper left) debuted in 1993 and had 3.1 million transistors. It used a technique called branch prediction to forecast upcoming instructions, so it could execute them more quickly. It was also designed with multimedia processing in mind. In the same year, IBM introduced the PowerPC 601 (upper right), with more than 2.8 million transistors. Developed jointly with Apple and Motorola, the chip was used in the Apple Power Macs. In 2000, Intel unveiled the Pentium 4 chip (opposite), a completely new design; it had 42 million transistors. The two distinct blocks on the right are part of its cache.

COURTESY OF INTEL, TOM WAY

COURTESY OF INTEL



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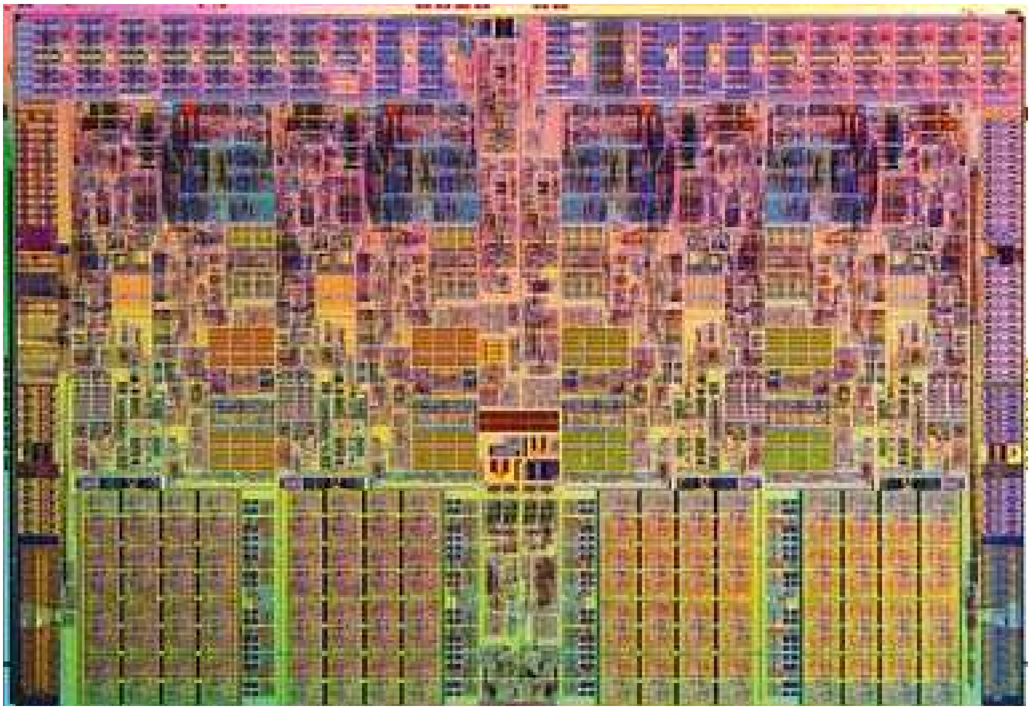
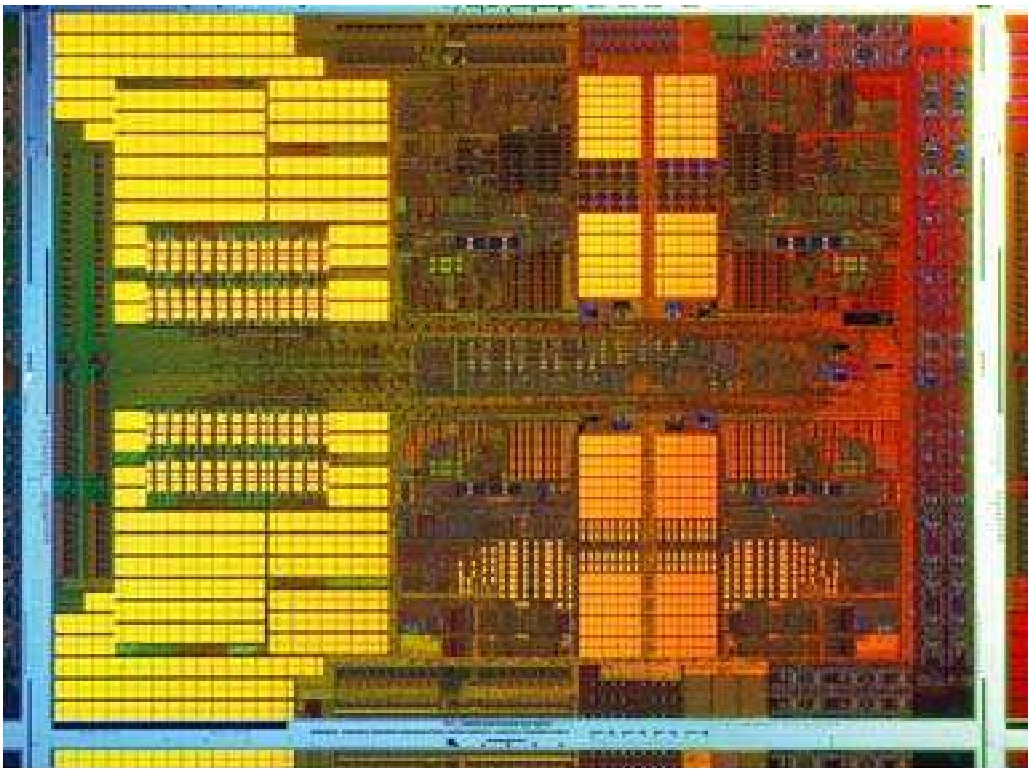




COURTESY OF INTEL, AMD

Some of the latest chips improve performance by incorporating more than one "core"—the part of the chip that handles instructions—into a single circuit. Putting multiple cores on a chip is one way manufacturers have been able to increase transistor count without also increasing power consumption. Intel's 2007 Core 2 Duo (opposite) has 410 million transistors and a large data cache (big orange block). The new Core i7 (top) is Intel's latest four-core chip, with roughly 731 million transistors. It has a shared cache (block along the bottom); its cores, above the cache, make up most of the rest of the chip. AMD's Phenom II (bottom), scheduled for release in early 2009, has four cores (flanking the rightmost yellow blocks), a large shared cache, and around 758 million transistors.

Lifeline for Renewable Power

WITHOUT A RADICALLY EXPANDED AND SMARTER ELECTRICAL GRID, WIND AND SOLAR WILL REMAIN NICHE POWER SOURCES.

By DAVID TALBOT

Photographs by EWAN BURNS

GREEN LINES
Tapping energy from remote wind and solar farms will require more high-voltage transmission lines like these, near Yermo, CA, which link southern Nevada with Los Angeles.

Push through a bulletproof revolving door in a nondescript building in a dreary patch of the former East Berlin and you enter the control center for Vattenfall Europe Transmission, the company that controls northeastern Germany's electrical grid. A monitor displaying a diagram of that grid takes up most of one wall. A series of smaller screens show the real-time output of regional wind turbines and the output that had been predicted the previous day. Germany is the world's largest user of wind energy, with enough turbines to produce 22,250 megawatts of electricity. That's roughly the equivalent of the output from 22 coal plants—enough to meet about 6 percent of Germany's needs. And because Vattenfall's service area produces 41 percent of German wind energy, the control room is a critical proving ground for the grid's ability to handle renewable power.

BACK TO BASICS Ramping up renewable energy in the U.S. won't require new technology so much as basic infrastructure—such as this substation near Santa Clarita, CA—to help bring that energy to market.

Like all electrical grids, the one that Vattenfall manages must continually match power production to demand from homes, offices, and factories. The challenge is to maintain a stable power supply while incorporating electricity from a source as erratic as wind. If there's too little wind-generated power, the company's engineers might have to start up fossil-fueled power plants on short notice, an inefficient process. If there's too much, it could overload the system, causing blackouts or forcing plants to shut down.

The engineers have few options, however. The grid has a limited ability to shunt extra power to other regions, and it has no energy-storage capacity beyond a handful of small facilities that pump water into uphill reservoirs and then release it through turbines during periods of peak demand. So each morning, as offices and factories switch their power on, the engineers must use wind predictions to help decide how much electricity conventional plants should start producing.

But those predictions are far from perfect. As more and more wind turbines pop up in Germany, so do overloads and shortages caused by unexpected changes in wind level. In 2007, Vattenfall's engineers had to scrap their daily scheduling plans roughly every other day to reconfigure electricity supplies on the fly; in early 2008, such changes became necessary every day. Power plants had to cycle on and off inefficiently, and the company had to make emergency electricity purchases at high prices. Days of very high wind and low demand even forced the Vattenfall workers to quickly shut the wind farms down.

Vattenfall's problems are a preview of the immense challenges ahead as power from renewable sources, mainly wind and solar, starts to play a bigger role around the world. To make use of this clean energy, we'll need more transmission lines that can transport power from one region to another and connect energy-hungry cities with the remote areas where much of our renewable power is likely to be generated. We'll also need far smarter controls throughout the distribution system—technologies that can store extra electricity from wind farms in the batteries of plug-in hybrid cars, for example, or remotely turn power-hungry appliances on and off as the energy supply rises and falls.

If these grid upgrades don't happen, new renewable-power projects could be stalled, because they would place unacceptable stresses on existing electrical systems. According to a recent study funded by the European Commission, growing electricity pro-

While its size and complexity have grown immensely, the grid's basic structure has changed little since Thomas Edison switched on a distribution system serving 59 customers in lower Manhattan in 1882.

duction from wind (new facilities slated for the North and Baltic Seas could add another 25,000 megawatts to Germany's grid by 2030) could at times cause massive overloads. In the United States, the North American Electric Reliability Corporation, a nongovernmental organization set up to regulate the industry after a huge 1965 blackout, made a similar warning in November. "We are already operating the system closer to the edge than in the past," says the group's president, Rick Sergel. "We simply do not have the transmission capacity available to properly integrate new renewable resources."

The challenge facing the United States is particularly striking. Whereas Germany already gets 14 percent of its electricity from renewable sources, the United States gets only about 1 percent of its electricity from wind, solar, and geothermal power combined. But more than half the states have set ambitious goals for increasing the use of renewables, and president-elect Barack Obama wants 10 percent of the nation's electricity to come from renewable sources by the end of his first term, rising to 25 percent by 2025. Yet unlike Germany, which has begun planning for new transmission lines and passing new laws meant to accelerate their construction, the United States has no national effort under way to modernize its system. "A failure to improve our grid will be a significant burden for the development of new renewable technologies," says Vinod Khosla, founder of Khosla Ventures, a venture capital firm in Menlo Park, CA, that has invested heavily in energy technologies.

GRIDLOCK

When its construction began in the late 19th century, the U.S. electrical grid was meant to bring the cheapest power to the most people. Over the past century, regional monopolies and government agencies have built power plants—mostly fossil-fueled—as close to population centers as possible. They've also built transmission and distribution networks designed to serve each region's electricity consumers. A patchwork system has developed, and what connections exist between local networks are meant mainly as backstops against power outages. Today, the United States' grid encompasses 164,000 miles of high-voltage transmission lines—those familiar rows of steel towers that carry electricity from power plants to substations—and more than 5,000 local distribution networks. But while its size and complexity have grown immensely, the grid's basic structure has changed little since Thomas Edison switched on a distribution system serving 59 customers in lower Manhattan in 1882. "If Edison would wake up today, and he looked at the grid, he would say, 'That is where I left it,'" says Guido Bartels, general manager of the IBM Global Energy and Utilities Industry group.

While this structure has served remarkably well to deliver cheap power to a broad population, it's not particularly well suited to fluctuating power sources like solar and wind. First of all, the transmission lines aren't in the right places. The gusty plains of the Midwest and the sun-baked deserts of the Southwest—areas that could theoretically provide the entire nation with wind and solar power—are at tail ends of the grid, isolated from the fat arteries that supply power to, say, Chicago or Los Angeles. Second, the grid lacks the storage capacity to handle variability—to turn a source like solar power, which generates no energy at night and little dur-

ing cloudy days, into a consistent source of electricity. And finally, the grid is, for the most part, a "dumb" one-way system. Consider that when power goes out on your street, the utility probably won't know about it unless you or one of your neighbors picks up the phone. That's not the kind of system that could monitor and manage the fluctuating output of rooftop solar panels or distributed wind turbines.

The U.S. grid's regulatory structure is just as antiquated. While the Federal Energy Regulatory Commission (FERC) can approve utilities' requests for electricity rates and license transmission across state lines, individual states retain control over whether and where major transmission lines actually get built. In the 1990s, many states revised their regulations in an attempt to introduce competition into the energy marketplace. Utilities had to open up their transmission lines to other power producers. One effect of these regulatory moves was that companies had less incentive to invest in the grid than in new power plants, and no one had a clear responsibility for expanding the transmission infrastructure. At the same time, the more open market meant that producers began trying to sell power to regions farther away, placing new burdens on existing connections between networks. The result has been a national transmission shortage.

These problems may now be the biggest obstacle to wider use of renewable energy, which otherwise looks increasingly viable. Researchers at the National Renewable Energy Laboratory in Golden, CO, have concluded that there's no technical or economic reason why the United States couldn't get 20 percent of its electricity from wind turbines by 2030. The researchers calculate, however, that reaching this goal would require a $60 billion investment in 12,650 miles of new transmission lines to plug wind farms into the grid and help balance their output with that of other electricity sources and with consumer demand. The inadequate grid infrastructure "is by far the number one issue with regard to expanding wind," says Steve Specker, president of the Electric Power Research Institute (EPRI) in Palo Alto, CA, the industry's research facility. "It's already starting to restrict some of the potential growth of wind in some parts of the West."

The Midwest Independent Transmission System Operator, which manages the grid in a region covering portions of 15 states from Pennsylvania to Montana, has received hundreds of applications for grid connections from would-be energy developers whose proposed wind projects would collectively generate 67,000 megawatts of power. That's more than 14 times as much wind power as the region produces now, and much more than it could consume on its own; it would represent about 6 percent of total U.S. electricity consumption. But the existing transmission system doesn't have the capacity to get that much electricity to the parts of the country that need it. In many of the states in the region, there's no particular urgency to move things along, since each has all the power it needs. So most of the applications for grid connections are simply waiting in line, some stymied by the lack of infrastructure and others by bureaucratic and regulatory delays.

WWW See a GE researcher demonstrate how smart-grid technologies work: **technologyreview.com/grid**

Lisa Daniels, for example, waited three years for a grid connection for a planned development of 9 to 12 turbines on her land in Kenyon, MN, 60 miles south of Minneapolis. The installation would be capable of producing 18 megawatts of power. Its site—only a mile and a half from a substation—is "bulldozer ready," says Daniels, who is also executive director of a regional nonprofit that aims to encourage local wind projects. "The system should be plug-and-play, but it's not," she says.

Utilities, however, are reluctant to build new transmission capacity until they know that the power output of remote wind and solar farms will justify it. At the same time, renewable-energy investors are reluctant to build new wind or solar farms until they know they can get their power to market. Most often, they choose to wait for new transmission capacity before bothering to make proposals, says Suedeen Kelly, a FERC commissioner. "It is a chicken-and-egg type of thing," she says.

MORE INTELLIGENCE

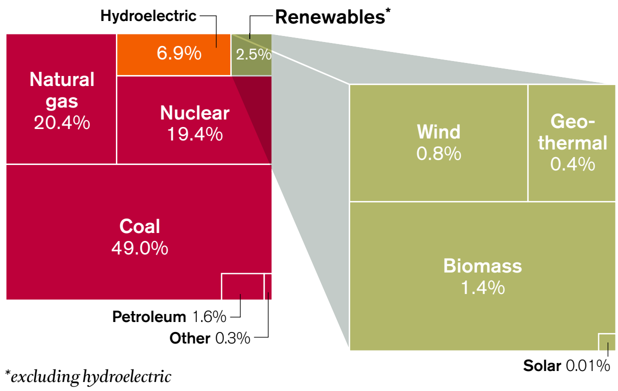
The windowless laboratory at GE Global Research in Niskayuna, NY, is stocked with kitchen appliances and lined with wall screens like those in the control centers for an electrical grid. In the lab, Juan de Bedout, manager of the Electric Power and Propulsion Systems Laboratory, describes how a "smart grid" could help make renewables practical. Imagine, he says, that the wind speed suddenly drops at a wind farm, or that a cloud bank moves over a photovoltaic installation. Existing transmission control systems—like those at Vattenfall—will detect the drop in supply and order increases in power production from other sources, particularly natural-gas plants, which can be fired up quickly.

But in a smart grid, the controller could send a message down to a regional distribution system, seeking a reduction in demand. Instantly, a signal would go out to meters in the homes or offices of customers who had agreed, in exchange for rate reductions, to let the utility rig some of their appliances to cut power consumption during supply drop-offs. Within seconds, electric water heaters would shut off for a few minutes, and electronic thermostats would be automatically adjusted by two or three degrees. There would be no need to power up the natural-gas plant.

In one of the more advanced pilot projects testing such a system, the Minneapolis-based utility Xcel Energy and several vendors are investing $100 million to install a smart-grid infrastructure in Boulder, CO. These days, a 115-person Xcel crew is out full time,

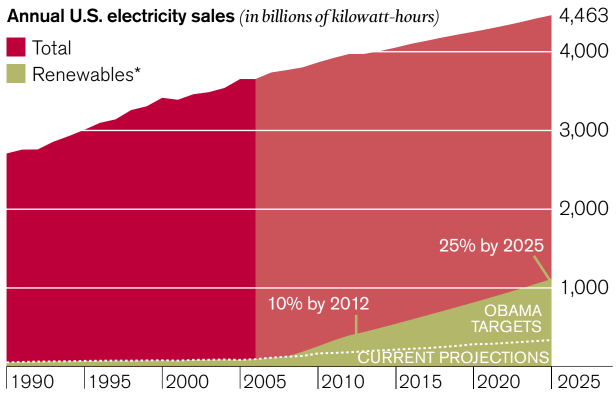
NEEDED: A GRID FOR RENEWABLE POWER

Sources of U.S. electricity
Today, renewable sources provide little U.S. electricity. Wind and solar together furnish less than 1 percent ...



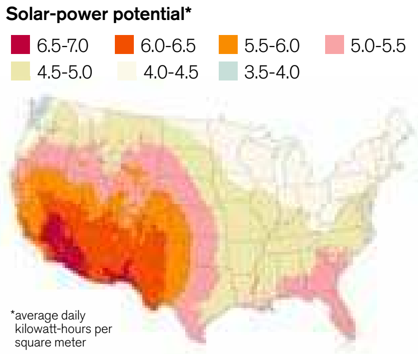
*excluding hydroelectric

Growing electricity demand
... but the fraction coming from renewable sources is projected to rise sharply—as is total demand.



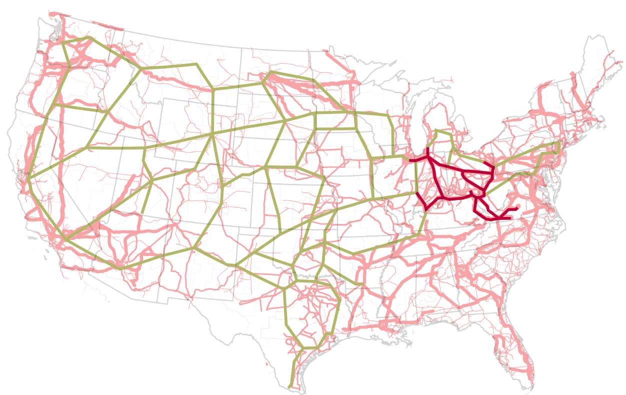
Onshore wind-power resources
The strongest, steadiest winds are concentrated in the Great Plains ...

Solar-power resources
... and the strongest, clearest sun exposure is in the Southwest ...



Today's electricity grid
... but existing transmission lines are centered on areas of high population, with inadequate high-voltage links to the areas with the best wind and solar resources. Fatter lines show higher-voltage connections.

Revamping the grid
Distributing wind and solar power produced in remote areas would require new transmission lines. This map shows one possible expansion of the grid: proposed lines are shown in green, existing ones in red. The U.S. Department of Energy says that it would cost about $60 billion to build enough new transmission capacity to let wind supply 20 percent of U.S. electricity. Former vice president Al Gore's proposal for a fossil-fuel-free electricity infrastructure calls for a $400 billion investment in transmission lines and smart-grid technology.



Sources: U.S. Energy Information Agency, National Renewable Energy Laboratory, American Electric Power (grid concept), and Obama campaign platform

TOMMY MCCALL

installing two-way electric meters at 50,000 houses. Homeowners are getting software that lets them view and manage their energy consumption on the Web, and some of their appliances are being fitted with switches that will let the utility shut them off remotely during periods of high demand.

Smart-grid technologies could reduce overall electricity consumption by 6 percent and peak demand by as much as 27 percent. The peak-demand reductions alone would save between $175 billion and $332 billion over 20 years, according to the Brattle Group, a consultancy in Cambridge, MA. Not only would lower demand free up transmission capacity, but the capital investment that would otherwise be needed for new conventional power plants could be redirected to renewables. That's because smart-grid technologies would make small installations of wind turbines and photovoltaic panels much more practical. "They will enable much larger amounts of renewables to be integrated on the grid and lower the effective overall system-wide cost of those renewables," says the Brattle Group's Peter Fox-Penner.

In Boulder, for example, Xcel is encouraging consumers to install solar panels on their roofs and banks of batteries in their basements—part of a plan to demonstrate how the variable power produced by thousands or millions of solar roofs could be stored in individual homes and fed into the grid when needed. In recent months, Xcel has even purchased a few plug-in hybrid cars and connected them to the grid, in order to test software that would let the vehicles act as energy-storage devices.

WIND BLAST Existing wind farms in southern California, like this one north of Santa Clarita, are being augmented by larger farms as new transmission lines link the area with greater Los Angeles.

> The gusty plains of the Midwest and the sun-baked deserts of the Southwest—which could theoretically provide the entire nation with wind and solar power—are at tail ends of the grid, isolated from the fat arteries that supply power to, say, Chicago or Los Angeles.

And Xcel is not alone. Startups and large companies alike are perfecting and commercializing solar roofing materials, basement energy-storage devices, batteries for plug-in hybrids, and clever software to optimize electricity use. But just as large-scale renewable-power generation depends on improving the transmission infrastructure, many of these advances are useless without better grid controls. You can't use a plug-in's battery for grid storage if the grid cannot intelligently retrieve power from the car.

The good news is that many utilities have begun installing the requisite meters—ones that intelligently monitor power flow out of a house as well as into it. The question now is how to move beyond the blizzard of pilot projects, install smarter technologies across the grid, and begin integrating more renewable power into the new infrastructure. "The smart-grid vision is nice; we all have our color PowerPoint slides," says Don Von Dollen, who manages intelligent-grid research at EPRI. "I think people kind of get the vision by now. Now it's time to get stuff done."

VICIOUS CIRCLE

Last summer, former vice president Al Gore began arguing that the country needed to implement an entirely carbon-free electricity system within a decade to avert the danger of global warming. As part of his vision, Gore called for a "unified national smart grid" that would move power generated from renewable sources to cities, increase the efficiency of electricity use, and allow for greater control over renewable resources. He estimated that the grid overhaul would cost $400 billion over 10 years.

Gore's plan doesn't spell out exactly how such a massive project would be executed. "If it's faster to have comprehensive legislation that gets states to work together and gets private capital to flow in, terrific," says Cathy Zoi, CEO of the Alliance for Climate Protection, the nonprofit that Gore founded in Menlo Park, CA, to press for urgent action on climate change. "If it's faster and easier to allocate federal money and do this as a public-works project, that's fine, too. We are not wedded to one policy instrument."

Right now, of course, neither strategy has been adopted. While pilot projects like the one in Boulder are worthwhile as a way to demonstrate new technologies, they've been implemented in hodgepodge fashion, with different utilities deploying different technologies in different states. Transmission projects are advancing incrementally, but they're often complicated by conflicts between the states. "What we have today is this patchwork of rules and regulations that vary by state," says Peter Corsell, CEO of GridPoint, a startup in Arlington, VA, that makes smart-grid software and is participating in the Boulder project. "We are all entrenched in this broken system, and there is no agreement on how to fix it. It's a vicious circle."

Some think that the answer is to give FERC more authority. Today, the agency can overrule states' decisions on where to site transmission lines, but only in regions that the U.S. Department of Energy has designated as critical for the security of the electricity supply. So far, only two such corridors have been designated: one in the mid-Atlantic states and another in the Southwest. Even in those regions, delays continue. Southern California Edison has proposed a major transmission line in the southwest corridor; stretching from outside Los Angeles to near Phoenix, AZ, it would be able to handle power generated by future photovoltaic and solar-thermal power plants. But Arizona rejected the idea, so the utility is preparing to take its plans to FERC.

Others think the solution is a new federal policy that would make the market for renewable power more lucrative, perhaps by regulating carbon dioxide emissions, as the cap-and-trade policy proposed by Obama would do. Under such a policy, wind energy and other carbon-free electricity sources would become much more valuable, providing an incentive for utilities to expand their capacity to handle them *(see "Q&A," p. 28)*. "It could all change very fast," says Will Kaul, vice president for transmission at Great River Energy in Minnesota, who heads a joint transmission planning effort that includes 11 utilities in the Midwest. "If there was a carbon policy, or a national renewable-energy standard, then the scale of wind generation would explode."

As Gore and other environmental experts warn—and as the engineers at Vattenfall would testify—an explosion in the use of renewables will depend heavily on upgrading the grid. That won't come cheap, but the payoff may be worth it. "We should think about this in the same way we think about the role of the federal highway system," says Ernest Moniz, a physics professor at MIT who heads the school's energy research initiative. "It is the key enabler to allow us to modernize our whole electricity production system. And renewables are an especially important beneficiary. There is no technology reason why we cannot move on this aggressively." TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

Interpreting the Genome

NEW TECHNOLOGIES WILL SOON MAKE IT POSSIBLE TO SEQUENCE THOUSANDS OF HUMAN GENOMES. NOW COMES THE HARD PART: UNDERSTANDING ALL THE DATA.

By EMILY SINGER

The 12 prototypes look like prefabricated children's forts—boxes the size of freezers, faced with bright red plastic and grouped in twos and threes on a concrete floor at Pacific Biosciences, a startup in Menlo Park, CA. But the simple exterior of the machines belies the complexity within. Each box houses a small chip packed with thousands of strands of DNA from bacteria or viruses, each strand in a nano-sized well. An enzyme stuck to the bottom of each well speedily builds a corresponding strand, stringing together the bases, or chemical subunits of DNA, that pair properly with those of the original. Each of the four types of bases, represented by the letters A, T, C, and G, is labeled with a different fluorescent marker, which is activated by the reaction that attaches a new base to the strand. Because the machine tracks the reactions as they happen, it can churn out reams of raw data on the sequences of the DNA samples as fast as a built-in camera can record them.

A computer monitor installed next to each machine displays a snapshot of the action taking place. A series of lights scatter across the screen, bursting and fading in quick succession. Each flash lasts just tens of milliseconds, but its color indicates which of the four bases has just been added to a strand of DNA, and its position indicates where. The video must be slowed for viewing: the flashes come too fast for the human eye to process. Computer algorithms convert the pattern of flashes into DNA sequences hundreds to thousands of bases long. Additional algorithms then compare millions of these stretches of DNA, identify sequences that overlap at their ends, and fit the pieces together to capture a complete genome.

When it comes to sequencing DNA, time is money, and Pacific Biosciences' commercial machines, due out in 2010, could prove to be the fastest ever made. It took the Human Genome Project roughly $300 million and 13 years to work out the sequence of the three billion DNA base pairs in a composite human genome, a task completed in 2003. By October 2008, researchers using a variety of new types of machines were saying that they could sequence an individual genome for less than $100,000; one company promises a $5,000 genome by next spring. And Pacific Biosciences predicts that by 2013, its machines will be able to sequence a person's genome in 15 minutes, for less than $1,000.

Up to now, scientists have sequenced the genomes of a handful of people, and that's given them a general sense of human variability. But fast, cheap sequencing technology could make it practical to read the genomes of thousands, perhaps millions, of people. By combing through those myriad genomes and linking specific DNA sequences to different characteristics—handedness, height, blood pressure, and susceptibility to anxiety, to name a few—scientists should be able to unravel the complex interplay of genetic variants that makes each individual unique. Most important, that kind of sequencing capacity might finally reveal the inherited basis of common diseases—a riddle that has been taunting geneticists for decades.

The actual impact on medicine, however, is far less certain and may be much less positive. For almost two decades, researchers have promised that advances in sequencing technology will enable doctors to practice personalized medicine, targeting treatments to patients on the basis of their genetic profiles. The assumption was that a limited number of common genetic variants would turn out to underlie a particular disease, and physicians would be able to prescribe drugs according to which variants their patients carried. But the latest data suggest that even the most common heritable illnesses, such as diabetes and heart disease, are linked to many different variants, each of them relatively rare. If that's true, then practicing personalized medicine could become very complicated—and very expensive. "It would not be good to have

Photograph by JUSTIN FANTL

SUPERFAST SEQUENCING
Prototype machines at Pacific Biosciences are being tested with bacterial DNA.

a $5,000 genome and a $500,000 analysis," says Francis Collins, the former director of the National Human Genome Research Institute and a leader of the Human Genome Project.

BEYOND COMMON VARIATIONS

Genomic medicine began in earnest in the 1980s, when scientists identified genes linked to diseases such as Duchenne muscular dystrophy and cystic fibrosis. Both are so-called Mendelian diseases, meaning that they're caused by mutations in a single gene; anyone who inherits either one or two copies of the mutated gene, depending on the disease, will be afflicted. Over the last 20 years, researchers have identified genes for a number of Mendelian disorders, and screening tests based on these discoveries have led to earlier diagnoses. In the case of disorders that develop only when a person inherits two copies of the mutation, the tests can identify healthy carriers, helping them make better-informed decisions about having children. Single-gene disorders, however, make up a very small percentage of human diseases. For most diseases, it's much harder to pinpoint the genetic culprits.

As scientists began assembling a rough draft of the genome sequence in the late 1990s, they uncovered a useful phenomenon. Large blocks of DNA, known as haplotype blocks, tended to be passed down intact through generations. Different versions of these blocks, which were linked to an individual's ancestral origins, had characteristic patterns of common genetic variations known as single-nucleotide polymorphisms (SNPs), in which the genetic sequence varies by just one DNA letter. Thus, a telltale SNP could serve as a marker for its surrounding DNA. The discovery was a boon to geneticists—if each block tended to occur in a limited number of varieties within the human population, it would be unnecessary to check every base in the genome for variations linked to common diseases such as asthma or schizophrenia. The presence of a particular SNP would indicate which haplotype block an individual carried.

Researchers developed genetic microarrays that could quickly detect the presence of these common SNPs throughout the genome; by scanning for the telltale variations, a relatively inexpensive process, the microarrays have enabled the largest genomic studies to date. Scientists have used them to efficiently search tens of thousands of human genomes for SNPs more common in people with autism or Alzheimer's, for example, than in healthy people. Over the last two years, a flood of studies have been published, identifying more than 300 genetic variations linked to an assortment of common traits and diseases.

But finding these variations has not led to the breakthrough that some scientists had hoped for in understanding the genetic basis of common diseases. That's because they turn out to account for only a small fraction of the genetic risk for many illnesses. Researchers have identified 18 genes linked to type 2 diabetes, for example, and tests to identify the variations have been introduced. Yet many other heritable risk factors for the disease remain unidentified. That means that the new tests give an incomplete picture of how likely someone is to develop diabetes, making it difficult to use them to tailor medical decisions. "There is very little reason to be encouraged that prevention strategies can be revolutionized with what we've discovered so far [on the genetic basis of common diseases]," says David Goldstein, director of the Center for Population Genomics and Pharmacogenetics at Duke University in Durham, NC.

The hunt for SNPs makes sense if the inherited risk for diseases like type 2 diabetes results from a combination of many common genetic variations, each exerting a small effect. But what if that is only part of the story? What if other, rarer types of genetic mutations are also playing a role? Because microarrays were designed to detect common SNPs, they miss variations that appear in less than 1 percent of the population. These mutations are the focus of an alternative hypothesis, in which—as in the Mendelian model—high-impact individual variations contribute heavily to a disease. Any one of the variations may occur infrequently, according to this thinking, but if they affect the same or related biochemical pathways, they may produce similar outcomes. Collectively, they could make a disorder relatively common.

Until recently, only limited efforts had been made to search for rare variants linked to common diseases. This search may involve sifting through every letter of DNA—something that can only be done by sequencing. With the old technology, that was too expensive to be practical. But in view of the disappointing results from microarray studies, scientists are turning to the fast new sequencing technologies to rigorously test the rare-variant hypothesis. It's likely that "much of the rest of the heritability [of disease] is hiding in rare variants with high impact," Collins says. "If we really want to understand the genomics of disease, we need complete genome sequences."

It's still unclear how much rare variations contribute to disease, but evidence is starting to trickle in. In a study published this summer, biologists at the University of California, Berkeley, sequenced the gene for an enzyme called MTHFR, which converts the B vitamin folate (folic acid) from one form into another. Scientists had previously identified a common genetic variant that produces a weakened version of the enzyme, increasing the risk of birth defects and possibly of heart disease. By sequencing the MTHFR gene in 564 people of different ethnicities, Nick Marini and colleagues found four new variants that also impair the enzyme's function; present in fewer than 1 percent of the subjects, these variants would have been undetectable in microarray studies.

WWW Take a tour of Pacific Biosciences' sequencing technology: **www.technologyreview.com/pgp**

> The latest data suggest that even the most common heritable illnesses are caused by many different variants, each of them relatively rare. If that's true, then practicing personalized medicine could become very complicated—and very expensive.

THE PERSONAL GENOME

At a recent conference at the venerable Cold Spring Harbor Laboratory on Long Island, James Watson, codiscoverer of the structure of DNA, sat slouched in the front row of the auditorium beneath a large portrait of himself. Watson, who for a time headed the Human Genome Project, had his genome sequenced in 2007. His was only the second individual genome to be completely mapped. (Craig Venter, who led the private effort to sequence the genome, used his own DNA as the sample.)

Watson isn't known for sitting through successive conference presentations. But a good portion of this conference was about him. He attended talk after talk, as scientists presented their analyses of what has become affectionately known as "Project Jim." Watson is a seemingly healthy 80-year-old man, and the results of scrutinizing his genome have so far been fairly mundane. He has extra copies of genetic variations shown in previous studies to protect against heart disease and macular degeneration, for example. An initially worrying mutation in the *BRCA1* gene, which is linked to breast cancer, turned out to be harmless. But the vast majority of Watson's genome remains uninterpretable. Scientists have yet to find a genetic component to his intelligence or his curiosity or his tendency toward politically incorrect outbursts. Perhaps most important to Watson, it's not yet clear whether he harbors a genetic vulnerability to schizophrenia that he passed along to his son, who has the disease.

The Human Genome Project's reference sequence, which is a composite of genetic information from more than 20 individuals, gave scientists a basic blueprint of the genome. But a single genome has its limits. It's only by comparing multiple genomes that scientists can begin to get a handle on the genetic variability that underlies the vulnerability to disease or madness, the tendency to athletic prowess or mathematical genius, the drive toward altruism or aggression.

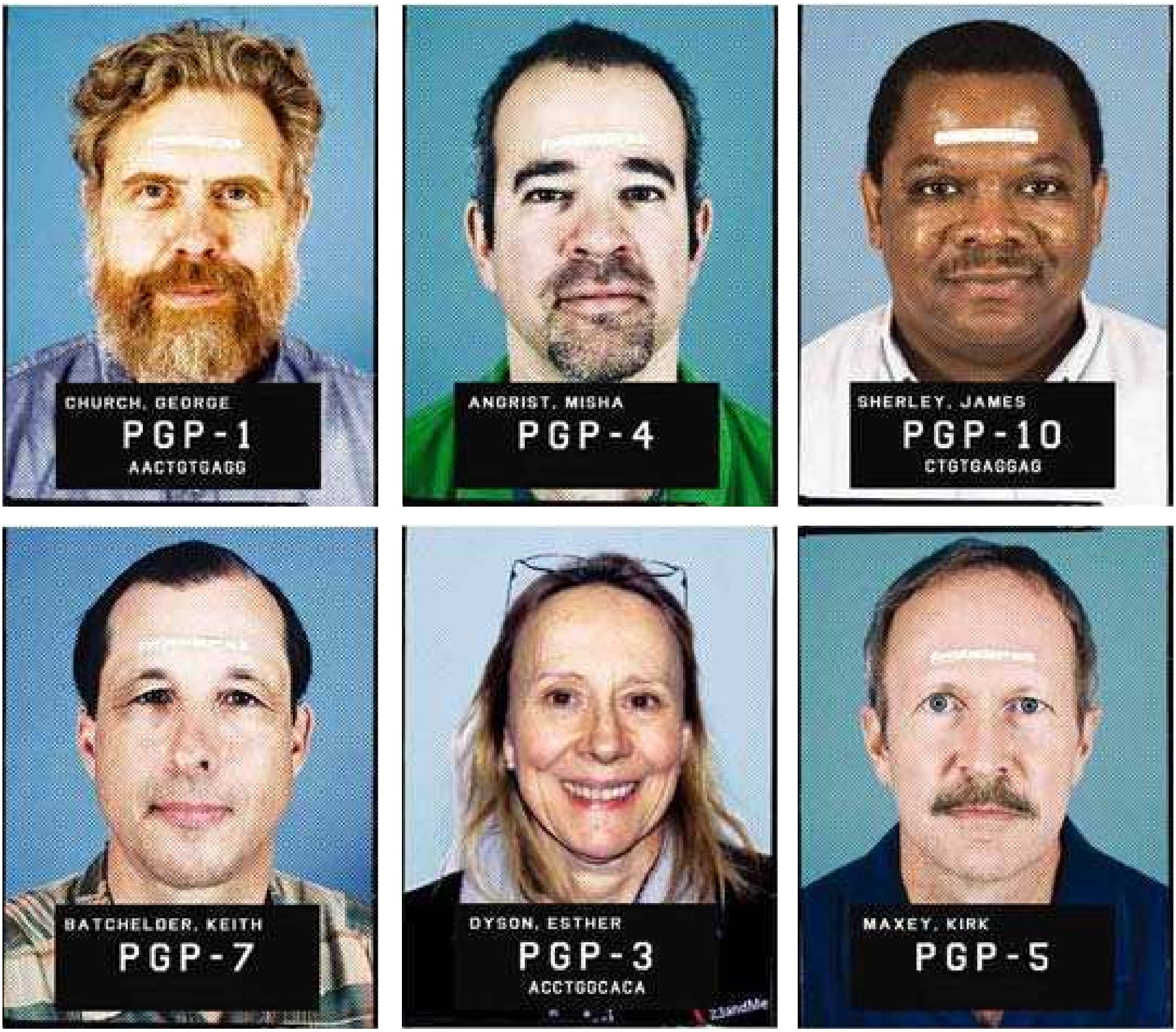
Even Watson, who has spent his career trying to understand DNA, seems less than impressed to see the details of his genome presented. "We'll see if any of it adds five minutes to my life span," he remarked at the conference. Indeed, the meaning of most of his genetic quirks will remain a mystery until many more people join him in having their genomes sequenced.

Harvard Medical School geneticist George Church, who has been working on sequencing technology since his PhD research at Harvard in the early 1980s, aims to speed that process along. Three years ago Church launched the Personal Genome Project (PGP), which aims to collect genetic and medical data from thousands of people over the next five years. The project indicates not just the technical and scientific challenges that might be posed by large-scale sequencing of human genomes, but the ethical issues as well.

In the pilot phase, the project will focus on 10 volunteers, including Church, Harvard psychologist Steven Pinker, and entrepreneur Esther Dyson. To start, it will sequence the coding regions of their genomes—the 1 percent of DNA that directs the production of proteins. That information, along with the participants' medical histories (including prescription regimens) and information about their height, weight, handedness, and other traits, will be deposited in a public database. Church's team hopes that this database will serve as a resource for scientists, or even members of the public, who want to search for links between specific genetic variations and diseases or other traits.

The first set of data—released to participants in October—hints at both the promise of sequencing and the current limitations of genetic analysis. John Halamka, CIO of Harvard Medical School and another one of the 10 original volunteers, learned that he carries a mutation for Charcot Marie-Tooth disease, an inherited neurological disorder. This rare variation would not have been found with existing SNP arrays. But since Halamka survived childhood unscathed, and only three other people in the world have been shown to carry that particular mutation, it's hard to know what impact, if any, it has had on his health. Perhaps many people carry the variation with no ill effect, and the link between the disease and the mutation has been overstated. Or perhaps the gene has a broader impact than expected, raising the risk of other neurological diseases. (Or, as George Church notes, the finding may simply be an error.)

The greater the number of entries in the database, the easier it will be to understand a finding like Halamka's. And in April 2008, Church's team received approval from Harvard to expand the project from 10 to 100,000 participants. (Church plans to scale up slowly, multiplying the number of subjects by 10 each year.) This next phase will seriously test both the technology used to sequence the genomes and the strategies used to interpret the resulting data. As of November, about a year into the project, PGP scientists had gotten only about a fifth of the way through sequencing the coding regions of the original volunteers' genomes. (Church plans to



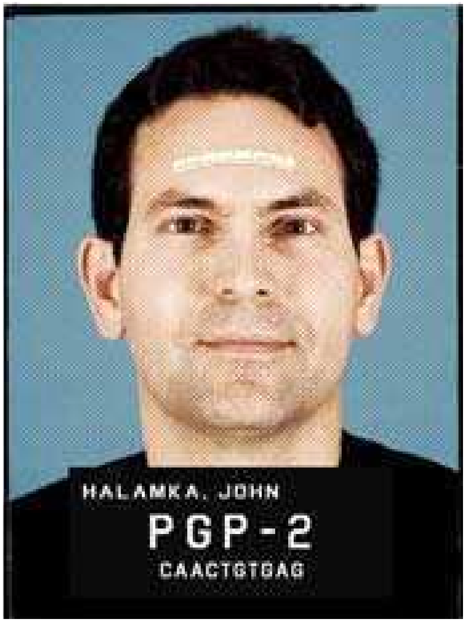
COURTESY OF PERSONALGENOMES.ORG

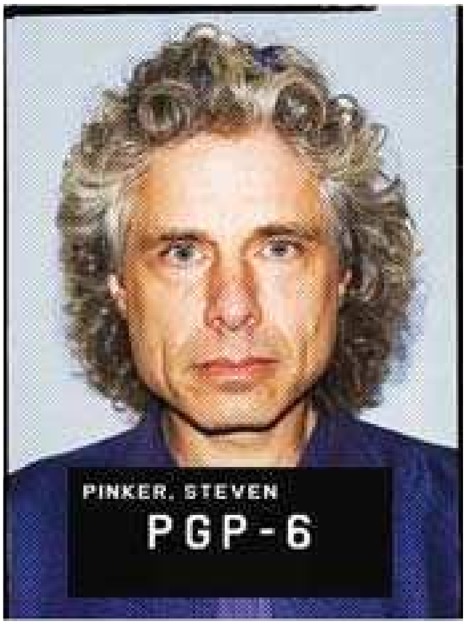
expand the PGP to the entire genome once sequencing becomes cheap enough.) If they're to sequence thousands more genomes, sequencing technology will need to become as fast and robust as Church believes it can be.

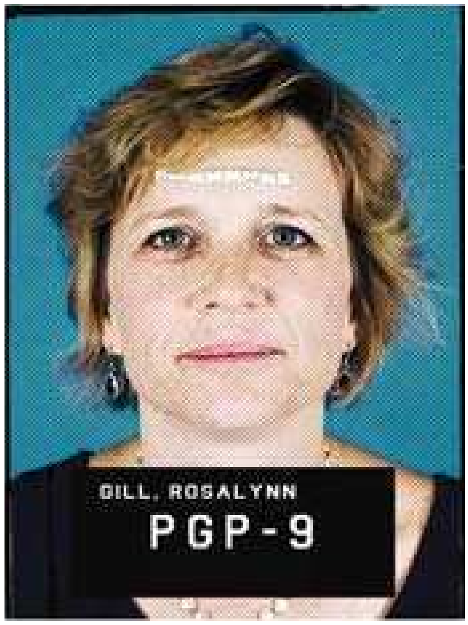
TOO MUCH INFORMATION

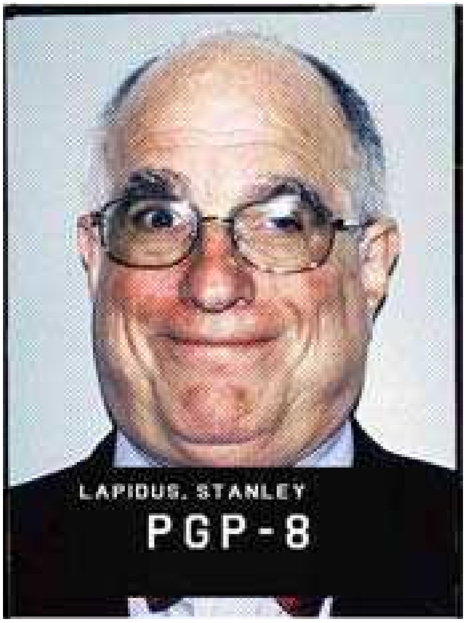
Making use of the data from the PGP will pose problems of its own. First, Church and his team will need to figure out the best way to give the larger group of volunteers their results. The first 10 received one-on-one genetic counseling from Joseph Thakuria, the project's medical director and a clinical geneticist at Harvard Medical School. But Thakuria won't be able to counsel the thousands of new subjects. Given the shortage of geneticists and genetic counselors with appropriate training, that problem is almost certain to be echoed much more broadly as personal genomics becomes more accessible.

But the greatest challenge in the next phase of human genomics is likely to be interpreting the meaning of the seemingly endless array of variations that will be uncovered. Individual genetic changes occur by chance, and some are harmless. Others happen to be dangerous, disrupting some vital cellular process and raising the risk of disease. And some may even be beneficial—enhancing the breakdown of toxins, for example, and thus protecting against certain ailments. But it's often impossible to tell which class a variation falls into just by looking at it. And as new technologies allow scientists to sequence the genomes of large









THE PGP 10 The first 10 volunteers in the Personal Genome Project are currently having the coding regions of their genomes sequenced; a small piece of sequence is shown for those whose data is posted online. The sequence data will be stored in a public database, along with the volunteers' medical records and other information, such as their facial morphology (as measured by the forehead tapes). Scientists will use the database, which is expected to eventually include 100,000 people, to search for links between genes and diseases or other characteristics.

numbers of people, the list of known variants will quickly grow. "This information is going to be thorny and problematic in terms of interpretation," says James Evans, a professor of genetics and medicine at the University of North Carolina at Chapel Hill. "We all have mutations and alterations that we simply don't understand. As usual, the technology will be ahead of our ability to use it."

The complexity of the new genomic information may also be an obstacle to the personalized medicine that gene sequencing was supposed to usher in. Researchers have hoped to create tests that predict an individual's risk for a specific disease or reveal which drug is likely to work best for him or her. But genetic tests that detect newly discovered variations won't be very useful until scientists can figure out what those variations mean. And if many common diseases are caused by rare variants, the task will be enormous. "Understanding risk based on rare variants is going to take us years," says Dietrich Stephan, founder and chief science officer of Navigenics, a personal-genomics startup.

Some scientists think that the real value of genomics may not lie in personalized medicine at all. Where it will really pay off, they say, will be in deepening our understanding of disease and helping researchers discover new targets for drugs. "The primary value of genetic mapping is not risk prediction, but providing novel insights about mechanisms of disease," wrote David Altshuler, a physician and geneticist at the Broad Institute in Cambridge, MA, in a recent article published in the journal *Science*. In fact, Altshuler points out, identifying even rare genetic changes can end up helping a large number of patients. For example, studies of an inherited form of high cholesterol found in less than 0.2 percent of the population led to the discovery of the low-density lipoprotein (LDL) receptor, which helps to remove excess cholesterol from the bloodstream. That in turn led to the development of the blockbuster drugs known as statins, cholesterol-lowering medications that trigger an increase in the number of LDL receptors on the surfaces of liver cells.

No one knows when the next blockbuster will arrive. Making predictions about the benefits of genomics has become as thankless as trying to predicting disease risk itself. And the easier it gets to sequence a genome, the harder it becomes to make sense of the complexity the sequences reveal. As Collins puts it, "The Human Genome Project was perhaps a simple undertaking compared to what we face next." TR

EMILY SINGER IS *TECHNOLOGY REVIEW*'S SENIOR BIOMEDICAL EDITOR.

Parallel Universe

TO MOVE FORWARD, INTEL DUSTS OFF OLD SUPERCOMPUTER TECHNOLOGY.

By ROBERT X. CRINGELY

When Anwar Ghuloum came to work at Intel in 2002, the company was supreme among chip makers, mainly because it was delivering processors that ran at higher and higher speeds. "We were already at three gigahertz with Pentium 4, and the road map called for future clock speeds of 10 gigahertz and beyond," recalls Ghuloum, who has a PhD from Carnegie Mellon and is now one of the company's principal engineers. In that same year, at Intel's developer conference, chief technology officer Pat Gelsinger said, "We're on track, by 2010, for 30-gigahertz devices, 10 nanometers or less, delivering a tera-instruction of performance." That's one trillion computer instructions per second.

But Gelsinger was wrong. Intel and its competitors are still making processors that top out at less than four gigahertz, and something around five gigahertz has come to be seen, at least for now, as the maximum feasible speed for silicon technology.

It's not as if Moore's Law—the idea that the number of transistors on a chip doubles every two years—has been repealed. Rather, unexpected problems with heat generation and power consumption have put a practical limit on processors' clock speeds, or the rate at which they can execute instructions. New technologies, such as spintronics (which uses the spin direction of a single electron to encode data) and quantum (or tunneling) transistors, may ultimately allow computers to run many times faster than they do now, while using much less power. But those technologies are at least a decade away from reaching the market, and they would require the replacement of semiconductor manufacturing lines that have cost many tens of billions of dollars to build.

So in order to make the most of the technologies at hand, chip makers are taking a different approach. The additional transistors predicted by Moore's Law are being used not to make individual processors run faster but to increase the number of processors inside a chip. Chips with two processors—or "cores"—are now the desktop standard, and four-core chips are increasingly common. In the long term, Intel envisions hundreds of cores per device.

But here's the thing: while the hardware problem of overheating chips lends itself nicely to the hardware solution of multicore computing, that solution gives rise in turn to a tricky software problem. How do you *program* for multiple processors? It's Anwar Ghuloum's job to figure that out, with the help of programming groups he manages in the United States and China.

Microprocessor companies take a huge risk in adopting the multicore strategy. If they can't find easy ways to write software for the new chips, they could lose the support of software developers. This is why Sony's multicore PlayStation 3 game machine was late to market and still has fewer game titles than its competitors.

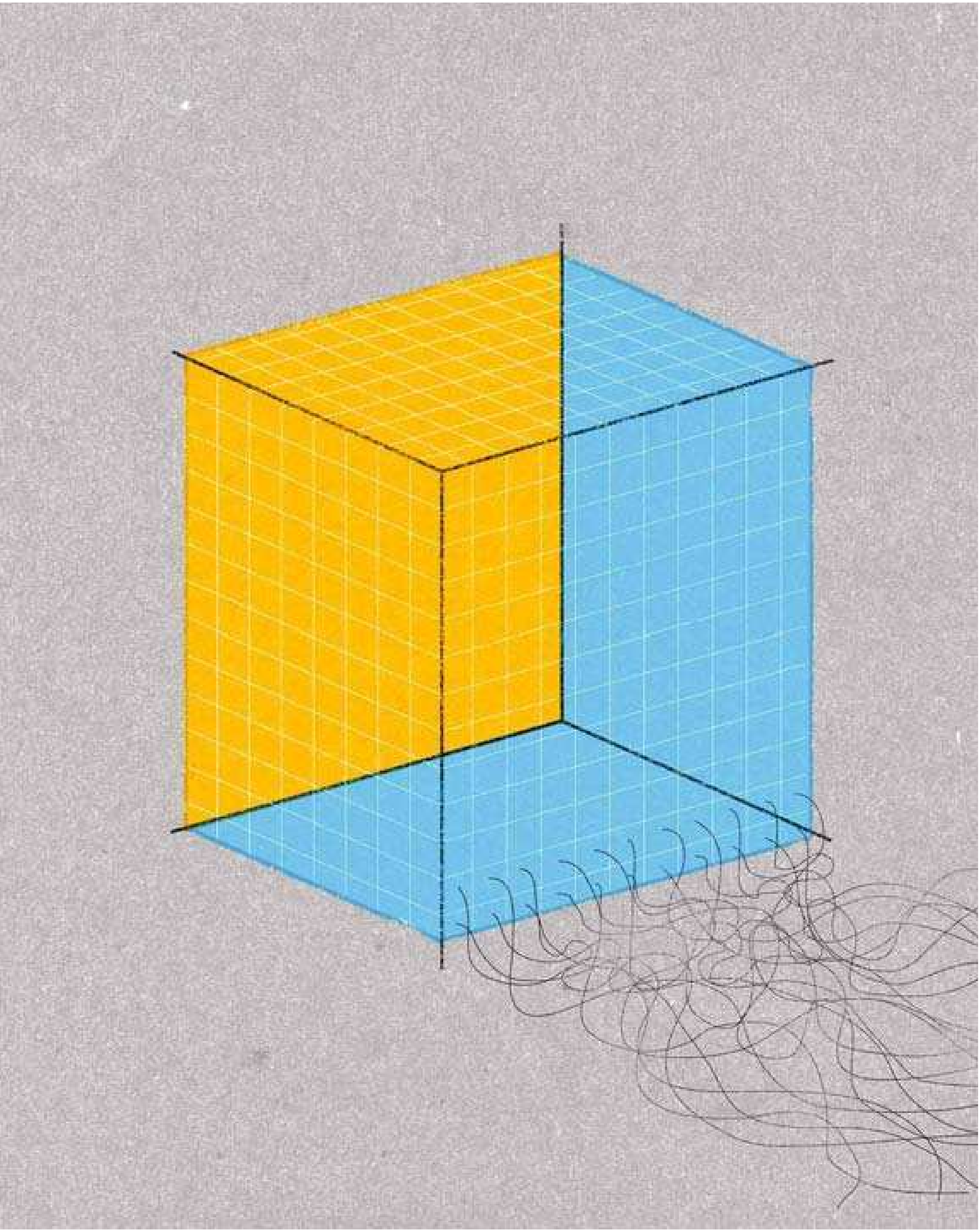
THE PROBLEM WITH SILICON

For the first 30 years of microprocessor development, the way to increase performance was to make chips that had smaller and smaller features and ran at higher and higher clock speeds. The original Apple II computer of 1977 used an eight-bit processor that ran at one megahertz. The PC standard today is a 64-bit chip running at 3.6 gigahertz—effectively, 28,800 times as fast. But that's where this trajectory seems to end. By around 2002, the smallest features that could be etched on a chip using photolithography had shrunk to 90 nanometers—a scale at which unforeseen effects caused much of the electricity pumped into each chip to simply leak out, making heat but doing no work at all. Meanwhile, transistors were crammed so tightly on chips that the heat they generated couldn't be absorbed and carried away. By the time clock speeds reached five gigahertz, the chip makers realized, chips would get so hot that without elaborate cooling systems, the silicon from which they were made would melt. The industry needed a different way to improve performance.

Because of the complex designs that high-speed single-core chips now require, multiple cores can deliver the same amount of processing power while consuming less electricity. Less electricity generates less heat. What's more, the use of multiple cores spreads out whatever heat there is.

Most computer programs, however, weren't designed with multiple cores in mind. Their instructions are executed in a linear sequence, with nothing happening in parallel. If your computer *seems* to be doing more than one thing at a time, that's because the

Illustration by THE HEADS OF STATE



processor switches between activities more quickly than you can comprehend. The easiest way to use multiple cores has thus been through a division of labor—for example, running the operating system on one core and an application on another. That doesn't require a whole new programming model, and it may work for today's chips, which have two or four cores. But what about tomorrow's, which may have 64 cores or more?

REVISITING OLD WORK

Fortunately, says Leslie Valiant, a professor of computer science and applied mathematics at Harvard University, the fundamentals of parallelism were worked out decades ago in the field of high-performance computing—which is to say, with supercomputers. "The challenge now," says Valiant, "is to find a way to make that old work useful."

The supercomputers that inspired multicore computing were second-generation devices of the 1980s, made by companies like Thinking Machines and Kendall Square Research. Those computers used off-the-shelf processors by the hundreds or even thousands, running them in parallel. Some were commissioned by the U.S. Defense Advanced Research Projects Agency as a cheaper alternative to Cray supercomputers. The lessons learned in programming these computers are a guide to making multicore programming work today. So Grand Theft Auto might soon benefit from software research done two decades ago to aid the design of hydrogen bombs.

In the 1980s, it became clear that the key problem of parallel computing is this: it's hard to tear software apart, so that it can be processed in parallel by hundreds of processors, and then put it back together in the proper sequence without allowing the intended result to be corrupted or lost. Computer scientists discovered that while some problems could easily be parallelized, others could not. Even when problems *could* be parallelized, the results might still be returned out of order, in what was called a "race condition." Imagine two operations running in parallel, one of which needs to finish before the other for the overall result to be correct. How do you ensure that the right one wins the race? Now imagine two thousand or two million such processes.

"What we learned from this earlier work in high-performance computing is that there *are* problems that lend themselves to parallelism, but that parallel applications are not easy to write," says Marc Snir, codirector of the Universal Parallel Computing Research Center (UPCRC) at the University of Illinois at Urbana-Champaign. Normally, programmers use specialized programming languages and tools to write instructions for the computer in terms that are easier for humans to understand than the *1*s and *0*s of binary code. But those languages were designed to represent linear sequences of operations; it's hard to organize thousands of parallel processes through a linear series of commands. To create parallel programs from scratch, what's needed are languages that allow programmers to write code without thinking about how to make it parallel—to program as usual while the software figures out how to distribute the instructions effectively across processors. "There aren't good tools yet to hide the parallelism or to make it obvious [how to achieve it]," Snir says.

BRIGHT LIGHTS In 1987, Thinking Machines released its CM-2 supercomputer (above), in which 64,000 processors ran in parallel. The company declared bankruptcy in 1994, but its impact on computing was significant.

To help solve such problems, companies have called back to service some graybeards of 1980s supercomputing. David Kuck, for example, is a University of Illinois professor emeritus well known as a developer of tools for parallel programming. Now he works on multicore programming for Intel. So does an entire team hired from the former Digital Equipment Corporation; in a previous professional life, it developed Digital's implementation of the message passing interface (MPI), the dominant software standard for multimachine supercomputing today.

In one sense, these old players have it easier than they did the last time around. That's because many of today's multicore applications are very different from those imagined by the legendary mainframe designer Gene Amdahl, who theorized that the gain in speed achievable by using multiple processors was limited by the degree to which a given program could be parallelized.

Computers are handling larger volumes of data than ever before, but their processing tasks are so ideally suited to parallelization that the constraints of Amdahl's Law—described in 1967—are beginning to feel like no constraints at all. The simplest example of a massively parallel task is the brute-force determination of an unknown password by trying all possible character combinations. Dividing the potential solutions among 1,000 processors can't help but be 1,000 times faster. The same goes for today's processor-intensive applications for encoding video and audio data. Compressing movie frames in parallel is almost perfectly efficient. But if parallel processing is easier to find uses for today, it's not necessarily much easier to do. Making it easier will require a concerted

effort from chip makers, software developers, and academic computer scientists. Indeed, Illinois's UPCRC is funded by Microsoft and Intel—the two companies that have the most to gain if multicore computing succeeds, and the most to lose if it fails.

INVENTING NEW TOOLS

If software keeps getting more complex, it's not just because more features are being added to it; it's also because the code is built on more and more layers of abstraction that hide the complexity of what programmers are really doing. This is not mere bloat: programmers need abstractions in order to make basic binary code do the ever more advanced work we want it to do. When it comes to writing for parallel processors, though, programmers are using tools so rudimentary that James Larus, director of software architecture for the Data Center Futures project at Microsoft Research, likens them to the lowest-level and most difficult language a programmer can use.

"We couldn't imagine writing today's software in assembly language," he says. "But for some reason we think we can write parallel software of equal sophistication with the new and critical pieces written in what amounts to parallel assembly language. We can't."

That's why Microsoft is releasing parallel-programming tools as fast as it can. F#, for example, is Microsoft's parallel version of the general-purpose ML programming language. Not only does it parallelize certain functions, but it prevents them from interacting improperly, so parallel software becomes easier to write.

Intel, meanwhile, is sending Ghuloum abroad one week per month to talk with software developers about multicore architecture and parallel-programming models. "We've taken the philosophy that the parallel-programming 'problem' won't be solved in the next year or two and will require many incremental improvements—and a small number of leaps—to existing languages," Ghuloum says. "I also tend to think we can't do this in a vacuum; that is, without significant programmer feedback, we will undoubtedly end up with the wrong thing in some way."

In both the commercial and the open-source markets, other new languages and tools either tap the power of multicore processing or mask its complexity. Among these are Google's MapReduce framework, which makes it easier to run parallel computations over clusters of computers, and Hadoop, an open-source implementation of MapReduce that can distribute applications across thousands of nodes. New programming languages like Clojure and Erlang were designed from the ground up for parallel computing. The popular Facebook chat application was written partly in Erlang.

WWW Watch Robert Cringely explain multicore processing:
www.technologyreview.com/multicore

Meanwhile, MIT spinoff Cilk Arts can break programs written in the established language C++ into "threads" that can be executed in parallel on multiple cores. And St. Louis–based Appistry claims that its Enterprise Application Fabric automatically distributes applications for Microsoft's .Net programming framework across thousands of servers without requiring programmers to change a single line of their original code.

THE LIMITS OF MULTICORE COMPUTING

Just as Intel's dream of 10- and 30-gigahertz chips gave way to the pursuit of multicore computing, however, multicore itself might be around for a matter of years rather than decades. The efficiency of parallel systems declines with each added processor, as cores vie for the same data; there will come a point at which adding an additional core to a chip will actually slow it down. That may well set a practical limit on the multicore strategy long before we start buying hundred-core PCs.

Does it matter, though? While there may be applications that demand the power of many cores, most people aren't using those applications. Other than hard-core gamers, few people are complaining that their PCs are too slow. In fact, Microsoft has emphasized that Windows 7, the successor to the troubled Windows Vista, will use *less* processing power and memory than Vista—a move made necessary by the popularity of lower-power mobile computing platforms and the expected migration of PC applications to Internet-based servers. A cynic might say that the quest for ever-increasing processing power is strictly commercial—that semiconductor and computer companies, software vendors, and makers of mobile phones need us to buy new gizmos.

So what's the downside if multicore computing fails? What is the likely impact on our culture if we take a technical zig that should have been a zag and suddenly aren't capable of using all 64 processor cores in our future notebook computers?

"I can't wait!" says Steve Wozniak, the inventor of the Apple II. "The repeal of Moore's Law would create a renaissance for software development," he claims. "Only then will we finally be able to create software that will run on a stable and enduring platform."

"In schools," says Woz, "the life span of a desk is 25 years, a textbook is 10 years, and a computer is three years, tops. Which of these devices costs the most to buy and operate? Why, the PC, of course. Which has residual value when its useful life is over? Not the PC—it costs money to dispose of. At least books can be burned for heat. Until technology slows down enough for computing platforms to last long enough to be economically viable, they won't be truly intrinsic to education. So the end of Moore's Law, while it may look bad, would actually be very good." TR

ROBERT X. CRINGELY HAS WRITTEN ABOUT TECHNOLOGY FOR 30 YEARS. HE IS THE AUTHOR OF *ACCIDENTAL EMPIRES: HOW THE BOYS OF SILICON VALLEY MAKE THEIR MILLIONS, BATTLE FOREIGN COMPETITION, AND STILL CAN'T GET A DATE*.

ORAL HISTORY

"Very Stunning, Very Space, and Very Cool"

THE LAUNCH OF SPACE TOURISM

By ADAM FISHER

In 1995, Peter Diamandis founded the X Prize Foundation, which started a private space race by offering big money to the first group that could perform two manned suborbital flights within two weeks. In 1998, he cofounded Space Adventures Ltd. with $250,000 in seed capital and an even more audacious idea for bringing the private sector to bear on space exploration: tourism. It took three years of negotiations with the Russian authorities, but in 2001, former NASA engineer turned financier Dennis Tito flew to the International Space Station and back in a Soyuz capsule's third seat, next to the commander and engineer. Tito and Space Adventures opened the stars to anyone who could pay the freight.

Since Tito, five have followed. First was Mark Shuttleworth, a young South African Internet tycoon who was a key player in the rise of secure e-commerce. The second was Greg Olsen, a scientist who made his fortune developing near-infrared cameras. The first female space tourist, Anousheh Ansari, an Iranian-American telecommunications entrepreneur (and part of the family that sponsored the $10 million X Prize), flew third. Fourth was computer scientist Charles Simonyi, the former Microsoft executive responsible for Word and Excel. Finally, there was Richard Garriott, the son of a NASA astronaut, who's more famous as his alter ego, Lord British—a ruler in Ultima, the online world that he dreamed up. Space Adventures has brokered all of these trips, to a greater or lesser extent, and it claims to have sold $200 million worth of space travel so far.

Technology Review has set out to compile the first oral history of space tourism. We asked each of the five travelers who came after Tito to describe the trip. They gave hours of their time, sitting separately for multiple interviews over a six-month period. Most have never met, but they all told essentially the same story of blastoff, weightlessness, reëntry, and revelation. We've distilled, edited, and organized their words to create a composite story of what a space vacation is really like.

Garriott: I grew up in an astronaut household, and my right-hand next-door neighbor was Joe Engle, an astronaut. My left-hand neighbor was Hoot Gibson, another astronaut. I had another astronaut over the back fence, and many others in my one-block walk around the neighborhood as a kid. So I grew up believing everybody went to space, because everybody *did* go to space, if you know what I mean. It was a NASA physician who told me that my poor eyesight would prevent me from being selected as a NASA astronaut. While briefly that made me very sad, it also made me realize that if I was going to get to space, it was going to have to be through the route of privatization, not the route of government.

Shuttleworth: After the collapse of the Soviet Union, it was fairly clear that the Russian space program was going through a bit of a financial crisis, and there were rumors that they were talking to people about private flight. I tried getting hold of the Russian consulate in Cape Town but didn't have a lot of success.

Garriott: I had been investing in the privatization of space since I first began to make money in the computer games industry. I was one of the first investors in Space Adventures. I personally paid for the study to find out if it would be possible and how much it would cost. When [the Russian Federal Space Agency] came back with the price, I actually had the money and was prepared to go.

Shuttleworth: We went to Moscow, primarily to meet different players in the industry. The medical establishment, the military guys in Star City [site of the Gagarin Cosmonaut Training Center]. Dennis [Tito] hadn't flown yet.

Garriott: We began to move as if I was going to be the first civilian to fly in space. Unfortunately, that's also when the dot-com crash occurred, and of course, being a high-tech guy, all of my assets were in high tech. I got wiped out.

Shuttleworth: There was no standard deal. You had to negotiate with the folks who do the suits, the folks who do the medi-

REUTERS/SERGEI REMEZOV

HAPPY RETURN After 14 days in space, Charles Simonyi landed in Kazakhstan on April 21, 2007, rubber-legged.

SPACE SCHOOL Two months before his trip to the International Space Station, Charles Simonyi experiences zero gravity aboard a Russian aircraft (left). Anousheh Ansari, at the Gagarin Cosmonaut Training Center, studies Russian ahead of her flight (right).

MAXIM MARMUR/AFP/GETTY IMAGES (SIMONYI); EPSILON/GETTY IMAGES (ANSARI)

cal, the folks who do the training, the folks who provide the vehicle, the folks who do the in-flight monitoring, and the space agency as an overall body.

Garriott: We really did sell my seat to Dennis Tito. I got wiped out by the dot-com crash and had to rebuild in order to find my way back to space.

Olsen: It was June 18, 2003. I was sitting in Starbucks reading the *New York Times*, with a great big coffee. There was a story about Space Adventures. And I said, "Wow. This sounds like something I'd like to do!"

Simonyi: The way you get there is very simple. You call Space Adventures.

Olsen: I looked them up on the Web, and the next thing I knew, [Space Adventures CEO] Eric Anderson was at my door. We hit it off immediately. In October, they took me over to a launch in Baikonur [the Russian launch site, located in Kazakhstan]. I met some of the people in the Russian Space Agency. I visited Star City. I went up in a MiG-29 and really had the experience. That part was a freebie. It definitely whetted my appetite. After that, I said, "Yeah, wow! I want to go."

Shuttleworth: Space Adventures certainly helped with introductions, but I get a bit irritated when they present themselves as having facilitated everything.

Simonyi: I made the decision to go up very, very slowly. I actually went twice to Baikonur as a normal tourist, not a space tourist.

Olsen: I call it a "space participant." But call it space tourist if you want.

Garriott: Just for the record, I hate both of those terms. I prefer the term "private astronaut" or "private cosmonaut," or "civilian astronaut" or "civilian cosmonaut."

Simonyi: The launch is amazing just in terms of the kind of access that you get. We were partying next to the fully fueled rocket—practically touching it. We were laughing, talking, shouting greetings to the astronauts. It's very confidence inspiring. You know something that you can party around is not dangerous. It's a little bit like going onto a movie lot to watch the actor kissing the woman, and the director is saying, "Well you could be doing that." And I said, "You've got to be kidding." And then Anderson said, "No, no. We are working with a client right now."

Olsen: I had had a collapsed lung. They were obviously hyper about that. Made some issues about it. Finally, they accepted me in the program. In April of 2004, I went into training.

Simonyi: [Anderson] kind of just kind of looked at me and said, "Yeah, you could do it, I'm sure."

Ansari: I started training as a backup, not even knowing if I would fly. Simonyi was already in line to fly.

Shuttleworth: I had to build a support team in Star City. Because, again, there was nothing from Space Adventures. It was modeled on the little offices that the European Space Agency and NASA maintain there, but on a much smaller scale.

Simonyi: Now they've created this program [the Orbital Mission Explorers Circle], and you pay your money and then you get an option for a seat. You invest into a position in the queue, and then every time a seat comes up, you can pass or you can take it. It's a tradable position. You can sell your option for whatever the market will take. It's very thinly traded. I don't think any have traded yet. That guy [Google cofounder] Sergey Brin bought the first option.

Shuttleworth: The sticker price at my stage was $20 million. But the actual price paid is somewhat variable.

Garriott: Unfortunately, I am an insider, so I can't really get discounts. I paid $30 million.

Simonyi: The price is $35 million. It used to be $25, and now it's $35. The option price is much less. I bought an option—I said, "What the heck? I might want to go again!"

Shuttleworth: It's being streamlined now, because there have been quite a few folks who have gone through the process, and because Space Adventures has actually bought seats in anticipation of their use, which they hadn't done before.

Ansari: Three weeks before the flight, the guy who was flying, Dice-K [Daisuke Enomoto], the primary crew member, had some medical problems and failed one of his medical qualifications. That's when they offered me to take his place. As you can imagine, this is not one of those opportunities that comes that easily, so without hesitation—and out of disbelief in a way, too—I just had to say yes.

All those who decide to go to the International Space Station must learn Russian and train at Star City, near Moscow, for at least three months.

Ansari: When you go to Star City, it's down to basics, and sometimes not even basics.

Olsen: Star City used to be an air base; it's now a college for cosmonauts. It's a woodsy setting on a lake, a small village of about 3,000 people—a very idyllic place.

Garriott: There is an ambiance about the place that doesn't feel like a traditional American overly well-lit bright and shiny office. It's all a little dimmer and kind of surreal.

Ansari: Everything is on the verge of falling down.

Garriott: Nothing is wrong with old. I have been at NASA during some of their downturns and seen it in disrepair, too.

Ansari: The first day I came, there was no hot water. The next day, there was no hot water. I was going to the gym and taking showers over there. Finally I went down, and it's like, "Do you know when the hot water will come back?" They said, "Yeah, in about a month."

Olsen: The plumbing was a little rusty, so I had to get in and fix it, but I didn't mind.

Ansari: When you turn on the faucet, brown rusty water comes out. If you let it run for 10 or 15 minutes, it starts getting clear, and you can take a decent clean shower.

Olsen: It's kind of a culture shock.

Ansari: It is a military base. It taught me that you don't need a lot of things to live happily. At home I go to 10 different places to buy just that one product that I'm used to, that one shampoo.

Olsen: Things are real cheap at the store they have on base. Like, bread is maybe 20 cents U.S.

Ansari: I'm lactose intolerant, so I drink soy milk. But there's no soy milk over there on the military base.

Olsen: I ate at the cosmonaut cafeteria. Tea, hard-boiled eggs, and goulash was a typical breakfast, but I rolled with the punches. I wasn't there to live like an American.

Simonyi: I grew up in Hungary; also, I'm a programmer, so I eat anything. The food was perfectly good.

Olsen: I grew up during the Cold War. Now all of a sudden I'm living with the enemy, okay? It's a culture shock.

Simonyi: You run into people like Sergei Krikalyov. He's probably the all-time most-adapted human to space: 800 days, six times, he flew.

Olsen: The only English you hear is around the NASA section. I'm not going to tell you I'm fluent in Russian. By far that was the hardest part, learning Russian. Class was 9:00 to 4:00, including four hours of Russian three days a week. Then, 4:00 to 6:00, weights and all kinds of stuff in the gym. Then go home and study. And every Friday we had exams, oral exams. You can bet I burned the midnight oil before the exams. Boy, you talk about being nervous. The so-called multimillionaire American businessman who's a research scientist failing an exam!

Garriott: On the space station everybody speaks English, so it is no big deal. But on the Soyuz all the commands are in Russian, and all the instruments are labeled in Russian. So you want to get some fundamental mastery of Russian.

Shuttleworth: Four hours a day of intensive Russian is a little like brain surgery without anesthesia, but it was worth it. The faster you could get over that hump, the faster you could really start to interact.

Simonyi: Learning about the docking, communication, and reëntry systems was interesting.

Olsen: Sometimes I saw things that were a bit crude. They don't have the budget NASA has, so a lot of things that they do, they do by ingenuity.

Shuttleworth: The other day I got a little guided tour of a high-end racing yacht with carbon fiber walls and floor, computerized gadgetry and winches, stuff like that. Someone said, "Wow, this is just like a spaceship!" I laughed and said, "A spaceship is a hell of a lot simpler than this."

Simonyi: In the James Bond movies there's Q, who creates all these fantastic devices. It's not like that at all. Many of the devices on the spacecraft are almost from Jules Verne!

Shuttleworth: I was in training for a long time. I watched successions of NASA astronauts be very dismissive of the Soyuz. The worst thing I heard someone say was that if you got a small village together and asked them to design a spaceship, it would be like the Soyuz.

Garriott: You can look at the original Soyuz, and the same physical design—same molds, even—appear to have been used throughout its history. If it's not broken, don't fix it. But anything that has ever gone wrong or failed, they fix. Or if there is some new technology that comes along that would be of significant benefit, they change it also. The Soyuz has a glass [i.e., modern] cockpit, for example.

Shuttleworth: The NASA guys who went through the training program and actually got to the point where they could be a flight engineer or a commander, without exception, loved it. They suddenly realize that they can fly the damn thing without ground control, data feeds, and teams and teams of specialists.

Ansari: When it gets close to flight time, they take you to quarantine in Baikonur.

Olsen: We spend about 10 days there, so it's a bit boring. They were always giving you some kind of medical test.

Simonyi: The final checkout is in a doctor's office, with a medical team of three or four doctors. It's the most junior one who gives you the enema.

Garriott: The thing is to try to make sure you don't need to use the rest room on board the Soyuz.

Olsen: Here's the reason: on the Soyuz capsule, there's a facility for a bowel movement, but you really don't want to make a bowel movement on it. Imagine using a teapot to make a bowel movement. All right?

Shuttleworth: The most difficult period for me was the day before launch, because until that point it's just a complete whirlwind of activity. But during that final stretch, you have nothing to do but ponder. I remember going for a bit of a stroll when my phone rang. Very few people know that number. And I thought, "Wow. It's amazing how the universe works! I'm thinking about these difficult issues, and a member of my family or a close friend is calling!" I answered, and it was a wrong number. A lad from Africa had called. It was pretty funny: "No help there, mate. You've got to do this one on your own."

Garriott: Space travel is not the safest of all pastimes. But if you are going to fly, I like the Soyuz. If you look at the space shuttle, with two failures out of 150 launches or so, those are actually not great odds.

Shuttleworth: Soyuz failed early in the program and then had a safe run in, like, the last 30 or so flights.

Simonyi: Four people have died on the Soyuz. But in some sense their loss made the craft even safer.

Shuttleworth: I wouldn't say that the Soyuz program is getting safer and safer just because they have a flawless record over the last 20 years. I just didn't want the last thing that I thought when I got hit by a bus to be, "Damn, I should have gone."

The trip to the International Space Station begins with a bus ride to the launchpad and an elevator ride to a Soyuz capsule atop a Russian rocket the height of a 16-story building. There are rituals and customs that accompany every aspect of spaceflight, but never so many as on the day of a Russian launch.

Garriott: The Russians are a superstitious lot.

Olsen: A lot of traditions come from Yuri Gagarin [the first human in space]. When he was going out to the launch, he had to take a leak. They just didn't make any provisions for it. He said, "Stop the bus." He got off the bus and peed on the rear tire, and ever since then, that's mandatory.

Ansari: Fortunately, I found a way to excuse myself. I asked our commander [Mikhail Tyurin], "Can you just think of me while doing your business on the tire?" He said, "Of course I will do that for you, Anousheh. Anything."

Shuttleworth: You know, it took me a little while to go to the loo then. And people were teasing me, you know, about standing around and waving my willy at the girls in Kazakhstan.

Simonyi: It's a wonderful tradition. A great way to relax.

Ansari: Before the flight I was worried I would be a nervous wreck. I had told my flight surgeon, "If you see my blood pressure or my heart rate is high, don't let them stop the flight!"

Olsen: Even walking out to the launchpad, we had all of these heart monitors.

Garriott: You're walking to this fully fueled rocket, full of kerosene and oxygen. The thing is so cold it's covered with white frost. The air that's near it is coming streaming down the sides because it's cooler and denser. It's very clear that you are stepping into something that is on the edge, so to speak. And you climb on board.

Ansari: I was told that Greg Olsen was very calm.

Olsen: I had the lowest heart rate of any of us. Sixty beats per minute on launch.

Shuttleworth: He's telling that to everybody.

Ansari: I had to practice meditation, all sorts of things, to bring my pulse down.

Simonyi: Being in the Soyuz before launch is the greatest. You feel so centered, so comfortable. There's this nice humming noise. It smells fantastic. And you have plenty of time. The whole point, I think, is that there's no hurry. There's no pressure. They have these two words. One of them is *normalna,* which means "normal." The other one is *spakoyna,* which is like "easy" or "quiet." These are the chief words during that time.

Ansari: You sit there and you're like, "Oh my God, I'm finally here!" It's a surreal situation. You're like, "I'm actually sitting on top of a rocket. In a few minutes it will ignite, and I will be sent off with these amazing speeds into space." For someone who is a civilian, it's, like, unbelievable.

Simonyi: So you are there and they say, "You guys, we have about 30 minutes, and you have nothing to do. Do you want to listen to some music?" I said, "Sure." And so they were playing Abba's "Money, Money, Money," which I didn't recognize at first, but the other cosmonauts recognized it right away, and they were kind of nudging me. Yeah, everybody had a laugh.

Garriott: I would have called ours elevator music. Immediately what struck me is, "Here we are in the elevator to the heavens—listening to elevator music."

Olsen: If I could have had music? "Ride of the Valkyries."

Simonyi: In your hand is this checklist that is prepared on Microsoft Word and printed on a normal laser printer. It's nothing special. It's just this checklist held together by three rings. You basically just hear the checklist on the radio. All the commander does is look at the indications and reports, but the ground has the same indications. There are no activities for the crew.

Shuttleworth: It's a bit dull, to be honest. You're on a live mike, so you really don't want to be chattering away.

Garriott: I settled in the chair and took a nap. There is nothing happening during that 40-minute window. You are in this adrenaline lull. Then the radio comes back on, says "We are five minutes from launch," and stuff starts happening.

Olsen: Everything has a procedure when you take off. Step 1, Step 2, Step 3. And they follow it, one by one.

Simonyi: It's like going to the opera or the symphony. You take the score with you to understand what's going on. You appreciate more if you have the written score.

Garriott: Even before you can feel the thrust, you can feel that there is a massive amount of fluid shifting. Then the engines start some seconds prior to liftoff, so you can feel all that stuff power up. You can feel a bit of sway because of the wind. And then, right on time, right at launch moment, the Soyuz just very gently, but confidently, begins to step off the pad.

Olsen: Listen, when I felt that rocket rumbling, I got serenely peaceful. I'm thinking, "Yes! The next 10 days belong to me, and nobody can take this away from me."

Garriott: You are going, "Well, okay, if this goes well, it's going to be a gentle ride up. If this goes badly, hopefully that escape tower is going to work. Either way, life or death, it's going to be pretty raucous!"

and the very mechanical physical reality of it.

Ansari: The next thing I knew, this pen that was attached to a string started floating. It was just so crazy in my head. I was like, "Oh my God, I'm in space!"

Olsen: When you go weightless, one of the effects is that you have to urinate a lot because of fluid shift.

Simonyi: The fluids are behaving differently in the bladder.

Olsen: So, I'm dying to go, and finally I'm saying to myself, "Gee, I'm probably going to have to use this diaper. This might smell the capsule." I lean over to the commander—on the surface, he's like a stern Russian, but he's a great guy—and tell him, like I'm tipping him off.

Simonyi: In the capsule you communicate by nudges, because you all face forward and it's hard to turn your head. You can't see each other. But you can certainly feel the rest of their body. You are kind of pretty much just joined.

"You're walking to this fully fueled rocket, full of kerosene and oxygen. The thing is so cold it's covered with white frost. It's very clear that you are stepping into something that is on the edge, so to speak." —Richard Garriott

Shuttleworth: It's a profound experience. You're mixing moments of terror with moments of pure joy.

Olsen: At launch, we got to about three and a half G's. I tried to raise my arm, and it felt like I had a 10-pound weight on it.

Ansari: The pressure was not bad at all. Between the first stage and the second stage, it was like time stopped. Everything came to standing still for just a few seconds. Then it started back again. You get a kick there.

Olsen: After about eight minutes the G forces go away and you know you're going close to 17,000 miles an hour. It's a constant velocity, so there's no force.

Shuttleworth: The thing I remember as being quite striking was this collection of very domestic sounds that kicks in after the main-engine cutoff. Mechanical sounds, like the air circulation and the conditioning, and then bits and pieces are kind of kicking in. You've got alarm clocks and fans, and you've got a big device called the "globus." It's a ball—your map, basically—that turns, and it starts going *tick, tick, tick*, like a cuckoo clock. You've just gone through this extraordinary experience of getting up into space, and then suddenly it's like waking up inside the workshop of an old Swiss clockmaker or something. So it's this amazing contrast between what you might expect—which should involve special effects and background music—

Olsen: Then he leans over to me and says, in English, "Don't worry, Greg Olsen. I already went." Once I heard that, I just let go.

Garriott: I did wear and need a diaper during launch. You're psychologically motivated not to need it, but you quickly learn to get over your difficulty and use the device as designed.

Olsen: It didn't smell. Those diapers are well made.

Garriott: I don't think there is any way I could have gone the distance without it, so to speak.

Ansari: It took another while before they allowed us to take off the belts and be able to float in the cabin.

Simonyi: When you are weightless and in the seat, it's an interesting feeling, but not that big a deal. When I saw Oleg [the flight engineer] open the hatch above and fly out of his seat, through the hatch, and into the living room, that was amazing.

Olsen: We have this habitat module on the top.

Simonyi: There's this famous picture of Christ rising by the medieval painter [Matthias] Grünewald. It's just a fantastic painting, and these guys just floating like angels reminded me of it. It's amazing. And then you do it. I mean, it's fabulous.

Garriott: When you actually get a chance to look down at Earth from space, of course the view is spectacular. You can tell you're high because of the blackness of space, the curvature of the earth. But the view, at least looking straight down

to the ground, isn't that different from the view you might see out of an airplane window.

Simonyi: We had a Velcro curtain on the window. At one point I was trying to steal a glimpse of Earth, but [the commander] nudged me, and he raised his voice and ordered me to stop. In a real commander fashion.

Ansari: They really caution you the first couple of days about looking out the window, especially looking at the earth.

Simonyi: The Soyuz is put into a constant rotation so that the solar panels face the sun. Looking at the earth while the spacecraft is rotating can get you sick. You can get sick even if you don't look at the earth. That's called space adaptation syndrome. And that rotation exacerbates the effects of space adaptation syndrome. So for the first couple of orbits we weren't supposed to look at the earth.

Ansari: You have to take it really easy, move slowly, move your head slowly or don't move your head at all if possible. I felt great during the launch. I felt great right after the launch. Then it was time to sleep, and we set our sleeping bags.

Olsen: It's just, like, so weird when you sleep for the first time. I struggled to get to sleep, just because you're so excited. It's strange, and it feels good.

Simonyi: I was dreaming that I was on the ground. I'm in Star City just training, filling out this form, blah, blah, blah, blah, blah. And then I was awakened by the commander. I was kind of disoriented. Where am I? Oh, I'm in a spacecraft going around the earth!

Ansari: After I woke up, I was like, "Oh, it's my first day in space, first morning in space." I was so excited. I started flying out of my sleeping bag. Flying around, looking out the window. Going from one window to the other window.

Garriott: Just being able to flip and spin like an incredible professional gymnast and land with your face next to a window looking out at a big gorgeous sunrise is really fantastic.

Ansari: That's when the whole Soyuz started spinning around my head. I knew that I just did something I wasn't supposed to—and I got really ill.

Olsen: About 40 percent of all people who go into space do. It has nothing to do with being macho.

Ansari: I didn't let them see it. I thought, "Oh my God, they will think I'm stupid. I have my vomit floating around the cabin." I managed to grab a bag before it got too bad. I just had a little bit of it floating around. The good thing about it is it's floating, so you can catch it. I was able to catch it with a napkin and put it in the bag before they all could see it.

After two days of travel, the Soyuz capsule reaches low Earth orbit and begins to dock with the International Space Station.

Simonyi: Docking is fully automatic.

Olsen: The commander has the ability to take over the ship, but it's all done by radio controls. You're basically bouncing a radio beam off the ISS. That's telling you how far away you are, plus what velocity you're approaching the station at.

Simonyi: You start being aware of the presence of this incredible structure. You see it very small at first. And then you can see details of it, just through an optical sight. It's like a very old-fashioned—I don't know what it is. There is nothing, no items like that anymore, I'm sure. It's a periscope, in a sense, but you don't put your eye next to it. It's a projection on a matte glass: it has this faint, faint image. It's very sharp, of course, but it's not very bright.

Shuttleworth: I was focused on the periscope, because that's where it's approaching.

Simonyi: That instrument could have been constructed in the 19th century. Not the 20th century but the *19th* century.

Shuttleworth: It's sort of a functional minimalism. It would be very hard to break it.

Simonyi: Toward the very end, the retro-rockets fire. They just decrease the speed just by the tiniest amount. They pause more than fire, and the fire is just this white flash. But they fire right next to the side windows. And you can see this white flash and little bubbles, little globs of unburned propellant that go every which way.

Shuttleworth: I was intensely focused on the periscope, and after we docked, I looked out my window and suddenly the radiators and solar panels show up. There's this bloody great structure there, and it's very dramatic. You dock with the sun behind you, so it's very, very stark, and everything around it is completely black. It's very stunning, very space, and very cool.

Garriott: There's this iridescent, orange-ish glow from the solar panels that's just not captured in photographs.

Olsen: I remember we were right on target.

Garriott: The docking cone is designed to where you can be off target by even up to half a meter, really, and it will funnel you into the correct docking.

Ansari: They open the hatch toward the Soyuz first.

Olsen: Our hatch won't open. Our commander is pulling and pulling ... finally we put our feet on it. "One, two, three, heave. One, two, three, heave." It won't budge. I'm thinking, "All the training and money, and now we can't get the door open. We're going to have to go home." Then, finally, we cracked it.

Ansari: At that moment [the crew of the ISS] opens their door—to see how you look. If I was still sick, they didn't want to put me in front of the camera and embarrass me.

Simonyi: We shaved beforehand, put on clean flight suits.

Olsen: When we drifted into the ISS, the first thing I did was hit my head on the ceiling. This was on Moscow television.

Shuttleworth: On the one hand, it's kind of festive and welcom-

NO RESTART BUTTON Video game developer Richard Garriott is the most recent space tourist to take a ride on a Soyuz. This picture was taken during launch on October 12, 2008.

REUTERS/NASA TV

ing, and then on the other, it's kind of, "Shift over here to the camera and talk to the outside world."

Olsen: One tradition is they ring the bell. The first commander of the ISS was a navy guy, so he brought a ship's bell up to the ISS. Every time someone new came on, he'd ring the bell. Then the Russians have this tradition of giving you bread and salt when you arrive. Station commander Sergei Krikalyov gave us the bread and salt. I was awed just to be around him. He said, "How are you, Greg?" and gave me a big hug.

For the space tourists, there's not much to do aboard the ISS. They generally occupy themselves by taking snapshots, checking e-mail, and phoning home. Richard Garriott shot a sci-fi film starring his fellow astronauts and cosmonauts. And everyone on board spends a surprising amount of time simply looking for things.

Olsen: After we docked, shook hands, and said hello, there was about an hour when we could just sort of wander around.

Shuttleworth: When I was up there, there were, depending on how you count the nodes, five or six modules. They reach the size of a caravan. Some are larger, some smaller. The most interesting pieces are sort of off axis. There's a primary axis, which runs from the Russian habitation module through the storage module, through the American lab. And there were two things that hung off that. One was the docking module, and the other was what they call the front porch: the U.S. airlock.

Garriott: They gave me a little workstation near the ham radio in the service module and a little fold-down desk with a laptop on it, and I was like, "Wow, they've set me up in the middle of everyone else's business. I'm going to be constantly in people's way. It's going to be hard to film."

Simonyi: The commander tells you where you will stay, and in fact they gave me a bag for my stuff. I stuffed all my things in it and used the drawstring to secure it and attached it to the wall. Your home is basically invisible.

Ansari: I picked out a spot next to the window in the docking compartment. They told me that it was going to be cold and noisy. I said, "It doesn't matter—I want to be next to a window." They let me be there, and then they gave me this piece of cloth and the commander said, "Whenever you want privacy, just hang this, and we'll know not to come over." That made a nice private room for me.

Olsen: It's a lot like camping. Backpacking, actually.

Ansari: Cleaning yourself is an ordeal. There is no shower aboard the space station. You have these wet towels and dry towels that you use every day to wipe yourself, and a package with your personal toiletries up there—basically, your comb, your toothbrush, and whatever else they allow you to take up there.

Shuttleworth: I took a camera.

Simonyi: I took a paper tape of one of the first programs I ever wrote, and my passport.

Shuttleworth: That's quite a big tradition with the Russians. They have a stamp made for each ISS mission. People take postcards and envelopes and get them franked up there.

Olsen: I took an iPod, lots of photographs. My iPod, I had everything from opera to rock 'n' roll on there.

Garriott: I had a good friend, who writes the Dragonlance series of books for the company that makes Dungeons and Dragons, write me a screenplay. The story is basically that my mother had snuck up [to the space station] on the supply vehicle.

Ansari: The unmanned cargo mission that goes up before the manned flight takes some of your clothing, some of your food, a package that has your personal toiletries. But I wasn't supposed to be a primary member—Dice-K was. They said that they had changed it at the last minute, but when I got up there, the packages that they had sent up were still Dice-K's packages. I had his shaving cream, a razor, cologne, and things like that. They didn't have any of the things that I could use except for the toothbrush and the toothpaste. Fortunately, I took some stuff with me. I didn't have to wear his underwear.

Olsen: I had a little camera that I lost because I put it in my pocket and forgot to close the zipper.

Shuttleworth: The only thing I can recall going awry was breaking my camera up there. It was after hours and I was trying to get a night shot, and I put the memory card in the wrong way around or something. That was very frustrating.

Ansari: I was always losing things. I would write something, then put the pen down, forgetting that the pen would float off the table. I lost my lipstick, my lip gloss.

FROM THE LAB Anousheh Ansari with, left to right, Flight Engineer Mikhail Tyurin and Commander Michael Lopez-Alegria, in the laboratory module of the International Space Station.

REUTERS/NASA TV

Shuttleworth: Eventually, you learn to stick and then cover pretty much anything. Everything has Velcro on it. You want to make sure there are at least two points of attachment for anything that you happen to be working with.
Garriott: I had everything in bags within bags, Velcroed and zip-tied and rubber-banded.
Simonyi: When something goes drifting, it's very difficult to find. On Earth, when you lose something, you look on the floor. Here, you can't. You are looking at everything, and there is just stuff everywhere. It could be anywhere. Behind anything.
Shuttleworth: You'd often come across someone looking for something, and it would be floating just behind their head.
Simonyi: The space station is so messy. Words don't do justice. It's like going into the messiest hardware store you have ever seen—which only has one of everything somewhere in its inventory, okay? Try to find it—it's going to take you a while.
Shuttleworth: There are something like 17,000 pieces of loose equipment up there. You'd think that everything is documented, that everything has its fixed place, as it were. But it's just too big and complex for that.
Garriott: It is cluttered, but then after a while you realize, well, that's true if you're thinking in 2-D, but once your brain shifts to 3-D, you realize that it isn't. I'd be in the middle of filming, on camera in this fairly tight space, and people would cross the floor or the ceiling and not be bothering me at all, or vice versa.
Simonyi: If you leave something on the table, and then your worldview changes, now your wall becomes your floor. You don't automatically know where to look for the thing that you left on the table. It's like being in a different space. You don't necessarily recognize it. You can easily get disoriented.
Shuttleworth: Your body very strongly wants a sense of what's up and what's down, but those concepts are meaningless. What's interesting is that at some level, you maintain a sense of where the earth is. That's when you were most conscious of actually floating, because it felt like you were floating along horizontally. It wasn't so magical, but then being able to turn around and then dive into what felt like a well—the docking module, which was dropped down to Earth—that was pretty radical. Whereas the other piece off at an angle was the airlock, which was oriented off to the right, as it were, as you were moving down the very galaxy toward the U.S. end of the station. I had a good relationship with NASA, so there wasn't any sort of artificial constraint on where I was supposed to go and not supposed to go, which would have been weird.
Simonyi: I had an arrangement with NASA: I could call friends from space. Fantastic.
Olsen: The phone service is limited. It depends on where you are in relation to the communication satellites. But I would say on the average we only had maybe 10 minutes an hour. I was very conscious of the cosmonauts who'd been away from home for six months. In my opinion, they had priority over me, so I tried to be very respectful of their time.
Simonyi: It's a big deal for the astronauts and cosmonauts. The Russian space agency made the same deal; the cosmonauts could use those sort of Americanized assets. We have a headset plugged into a normal PC, and you go into Skype and you use the Skype interface.
Garriott: My first call was to my mother. The next call was to my girlfriend, Kelly, and her daughter. And then finally I made a call to the mayor of the city of Austin.
Olsen: With e-mail, NASA would only let addresses through that I already preapproved. I gave them a list of a hundred.
Simonyi: The thing about the e-mail is that—and you know, it's kind of sad—it had to be vetted by NASA. They worry about product promotion. And in fact, at one point I was writing a blog entry from the station, saying, "Wow, the champagne [on launch day] wasn't that great. The next time I will bring Dom Pérignon"—which I will. It was kind of a joke. I mean, I completely forgot. And so they caught it. To me it just seems so petty, so unnecessary. Is that what Mr. Spock is going to do? Explore new worlds and new civilizations and worry about whether somebody accidentally says "Dom Pérignon"? I mean, come on!

For working astronauts and cosmonauts, every minute of every day on the ISS is scheduled, so mealtimes are the one chance that the space tourists get to really interact with the natives.
Shuttleworth: We took turns making dinner. It was lovely.
Ansari: We had brought some fresh tomatoes and a few fresh fruits, and it was sort of a celebration.
Olsen: In general it's kind of like backpacking food. But the NASA shrimp cocktails were really good.
Simonyi: There's only one place to eat on the space station, which is in the Russian segment. That's where the heater is, the food heater. An oven, if you will.
Garriott: The galley table is covered with spoons that are standing up like trees, because they put double-sided tape on the

table. You can just tap the bottom end of your spoon handle on the table and it sticks there. That's one of the first lessons, the three-dimensional use of space.

Ansari: [Dinner] was my favorite time on board the station, because during the day, everyone is busy. This is the only chance you get to sit—of course, not sit, because there are no chairs to sit on—to float around the table and talk. For me, it was really great to debate some of my beliefs. Advertising, for example: What's wrong with it? I know especially NASA is dead against that, and I was arguing with some of them about it. "So what if you have a can of Coke here?" I asked. We had long arguments. I found them very interesting.

Garriott: It's very difficult to put six around the little dinner table. The dinner table is usually full with four or five people right-side up. Then one or two people the other way, using the ceiling as the floor.

Ansari: One of the first nights I was there, [the commander] asked me to pass the bread to him, because it was next to where I was standing. I took the bread and handed it to him. He was like, "No, that's not the way they do it in space. You have to throw it." I was like, "They told me not to throw food at anyone." "But you're not on Earth, you're in space. You have to throw it. You take the whole fun out of it, the way you do it."

Simonyi: Yeah, that's fun. Especially in the beginning, we kind of told our stories and reflected on what we were doing.

Garriott: I am here to tell you that one of the most common discussions amongst astronauts who live and work in space is the finer points of how to work with the life support systems, particularly the toilets. The Russian toilet actually works the best.

Olsen: [My doctor] asked me all the questions: "We got your heartbeat, any problems?" Blah, blah, blah. Third day, fourth day came: "You go yet, Greg?" "No." The fifth day: "No." He said, "Don't worry. World record is 14 days. You'll never beat it." It took me six days to go.

Garriott: A lot of people get constipated up there. But even if you don't, you are still going with very, very, low frequency. In my 12 days in space, I had to use the rest room three times.

Olsen: I remember we had this long conversation about what we were going to do when we got back. I was more enthralled with "Hey, I'm in space." But [Commander] Krikalyov and John Phillips [the NASA science officer] had been in space for six months now. They're getting really anxious. I remember Phillips said, "I just want beer and pizza. That would be it for me." Krikalyov joined in and said, "I just want to have a coffee, but not this crap we have here. I want the kind of coffee that I could hold to my nose and smell."

Simonyi: The returning crews are anxious to return. We were delayed by two days. They were up there for more than six months. I was celebrating: two extra days! And these guys were all, "Oh my God, I was supposed to be back. I was dreaming about this day, and now I have to wait two more days!"

Garriott: [My movie] begins with my actual departure from the space station with people waving. "Bye-bye, Richard, bye-bye." Then it goes to "Wow, man, I'm sure glad we got rid of that guy—all he would ever talk about is video games. Ultima this, Tabula Rasa that. Whew, glad he's gone." And after a bit of humorous life on board, they determine that there's too much oxygen being used for the number of crew that are currently on the station. So they believe an alien is on board, and they go searching for it, and instead they find my mother.

"The space station is so messy. Words don't do justice. It's like going into the messiest hardware store you have ever seen—which only has one of everything somewhere in its inventory, okay? Try to find it—it's going to take you a while." —*Charles Simonyi*

The flight back to Earth takes three and a half hours from undocking to landing, and on the way down, the Soyuz sheds two of its three sections. Both the service module, with its solar panels and communication equipment, and the habitation module (or "living room") burn up in the atmosphere. The heat-shielded reëntry module, containing the cosmonauts, deploys a succession of parachutes and retro-rockets to slow the spacecraft before impact.

Garriott: Packing up is a sad time. When you say your good-byes, they try to do that live on camera, and then they rush you off and undock quickly, for safety reasons. So it's really kind of a rushed and harried good-bye, which is really quite tearful.

Shuttleworth: I thought the flight down was the best bit of the whole thing. Just from the physics perspective, it's very dynamic. The launch is kind of sterile: you're 15 meters away from the engines, which is where all the action is. On the

NO WORSE FOR WEAR Inside the Soyuz, Mark Shuttleworth and crewmembers await extraction in Kazakhstan. Right, Greg Olsen gets a lift upon his return. Terminal velocity is about 25 miles per hour.

REUTERS/MIKHAIL GRACHYEV (CAPSULE); REUTERS/NASA/BILL INGALLS (OLSEN)

return, by contrast, the vehicle blows itself up and separates into all these pieces. And then this tiny little piece that has you in it comes straight back into the atmosphere with fireworks going off all around it. So you're in the thick of it.

Olsen: Remember that to land, the Soyuz is only one-third the size of what it is when it's launched, and most of the cargo space is missing. It has to be packed very carefully, because the mass distribution affects some of the aerodynamic characteristics of the Soyuz. It has to be done by the commander. This is the sort of thing we really want to help out on, but all you can do is stand by and watch, because it is a one-man thing, and it has to be done very carefully.

Simonyi: The living room is packed up with garbage so it will be burned up on return. The garbage bags are these rubberized bags that are closed with rubber rings just like the space suit—pretty much hermetically sealed.

Olsen: We put our space suits on, got in, and couldn't quite adjust the pressures between the habitat module, which is docked, and the docking compartment. For an hour we kept adjusting, and they finally said, "All right, let's go with it."

Simonyi: There's always pressure-integrity checks. It seems like that's all we do on the spacecraft: check pressure integrity. There's a very important instrument, a manometer—essentially a barometer, but for low pressure. It measures all the pressure on the spacecraft. It's big and brass, and it has these pipes that connect to everything. Again, it could literally have been constructed in the 19th century.

Olsen: Anyway, on our descent, we noticed that the pressure was dropping. We still don't know what happened, but some people think that a half-inch strap was lodged in the O-ring seal.

Simonyi: There was a valve that didn't close—it's anyone's guess why—and when the pressures dropped, these garbage bags started to explode. Can you imagine the mess? Oh my God!

Olsen: Finally Commander Krikalyov says, "Olsen, *kislorod*," which means "oxygen." I had to reach over to the oxygen valve. It's really difficult, because the valve is spring loaded. I held it open for about a minute, and finally the pressure came up to where it should be. But the problem now is that I'm enriching the air with oxygen. The normal air is roughly 21 percent oxygen. We got up to about 32 percent. If we reach 40 percent the cabin automatically depressurizes, because more than 40 percent oxygen tends to get spontaneous combustion.

Ansari: In most cases, something goes wrong.

Shuttleworth: The Soyuz is designed in a way where it has a very graceful degradation if things fail. Big chunks of subsystems can fail, and you can still make it home.

Simonyi: The critical point is when the three segments of the spacecraft separate and two segments are left to burn up.

Garriott: Separation really has three noises associated with it. First there is a kind of "pop" noise, which is a preseparation event—a disconnect of cables of some kind, or pipes. Then there is a pop where the habitation module is separated from in front of you. You can feel that force push you directly back with a nice, clean, smooth, directed-back movement. Another pop, and we separated from the instrument compartment. You can just feel if it's clean. Pop, pop, pop.

Simonyi: I could actually see parts of the spacecraft floating by the window. We were going Mach 20 or 22 in, like, the thinnest of thin air, but it was enough to make a sizable piece of insulation that was torn off by the separation kind of flap next to us. It was kind of slapping us in the wind, left and right. Then it hit our wall, and it kind of flew away.

Ansari: There was this orange glow, with sparks and things.

Simonyi: It looks like Pepto-Bismol. It's this solid pink plasma.

Garriott: It's like being on the inside of a blast furnace.

Ansari: Looking out the window, I blurted out, "My God, it feels like I'm riding a shooting star!"

Olsen: All of a sudden things start vibrating, and you can feel the deceleration. We get about four and a half G's, and it becomes hard to breathe. The capsule is being tossed around. There's no radio contact. You just kind of have to go through it.

Simonyi: It was getting dark, but in fact it was the window

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burning up that caused the darkness. The window has like three panes, and the outside pane is made to burn off a bit.

Shuttleworth: You're on your back, spinning around, and the G force is building up, and your vehicle is ablating away. It's intense. You've got to focus on the G forces building up.

Simonyi: The G forces are substantial but much easier to take than the G forces fighter pilots take, because it is through a different axis of your body. It's not down to your feet, but through your body, back and forth.

Garriott: The next big event is the opening of the drag chute, which can get a bit rough and tumble. Then when the main parachute opens, it's kind of like being at the end of a whip that has been cracked. Debris begins to scatter through the capsule even if it is really held down. Lots of projectiles.

Simonyi: I was entrusted to carry all the books, because the bookshelf was full of scientific stuff. Nobody seemed to be worried that I was carrying these books through impact.

Garriott: We were all in space suits with helmets closed, so we were all quite well protected.

Simonyi: Ten meters per second is your terminal velocity. Basically, you're running into a brick wall at 25 miles per hour.

Ansari: I thought it was going to be hard, but I never thought it was going to be this hard. The impact was shocking. You hit the ground so hard that the impact stops the blood flow. It felt like thousands of needles ran through my back.

Olsen: We bounced, we rolled a bit, we made some radio contact. We were instructed to wait for the search-and-rescue people. The next thing I know, I hear some banging on the capsule. They're just letting us know, "Hey, we're here."

Shuttleworth: You have to wait for the capsule to cool down. We were kind of impatient, so we opened up our visors.

Ansari: It gets really hot inside the capsule while you're coming down. You're hot and sweaty inside your space suits, and the whole experience really makes you feel disoriented. You're not used to gravity. You feel heavy. You can barely move.

Shuttleworth: The three of us were kind of staring out with our eyes wide open, smiling and looking at the hatch. In the impact, a whole spadeful of dirt had basically gone onto the hatch. And as they opened the hatch, we all got a face full of dirt. Sort of, "Welcome back to Earth." It was very funny.

Olsen: They just cut all the straps with knives, pulled us out, and put us in chairs.

Garriott: Even just 10 days in space and you really do lose the ability to really even stand up properly.

Ansari: It sort of reminded me of being born again.

Olsen: It was like when you graduate from college. You have this wonderful feeling of accomplishment. I really felt good about myself in a serene, secure way, not in an egotistical or bragging way, but just, "Wow."

Garriott: In training, you learn who has made what mistakes. And so you realize that if you make a mistake, your name will be used in association with that mistake for training for the rest of the history of the Russian space program.

Olsen: "Thank God I didn't screw up." That was my first thought when we landed, honestly.

Garriott: People have powered on or off things they shouldn't. Radios have been misconfigured. The toilet has been abused.

Simonyi: So anyway, we are in Kazakhstan, and then we take the helicopter to the airport, and then we take the plane back to Star City. I didn't take a bath that night. I just went to bed.

Olsen: First thing I did was have a shower. A shower and a shit, if you'll excuse me. Then I went back home. Now I look up and say, "Hey, there are my buddies, just floating up there."

Ansari: You're out there in space looking back at Earth, and in a way, you're also looking back at your life, yourself, your accomplishments. Thinking about everything you own, love, or care for, and everything else that happens around the world. Thinking bigger picture. Thinking in a more global fashion.

Simonyi: I don't think the purpose of spaceflight is to make better people. Because it will somehow change you or change your life–those are not the right reasons to go to space.

Garriott: I would agree with that, in principle.

Shuttleworth: For everybody, a year of your life in some odder circumstance is going to change you. That's kind of human nature. It's hard to put a finger on how, exactly.

Olsen: It's a life-changing experience in a subtle way. I mean, I'm not hugely spiritual or anything like that, but it's so much more than the flight. You make lifetime friends.

Simonyi: For example, Sergei [Krikalyov] is an amazing guy. I mean, he is so smart and so athletic. He's just a wonderful guy to be with, and so multifaceted. People don't appreciate how many people have flown multiple times. The top 10 people have 60 missions among them–six apiece.

Garriott: On the American side, I began to have what I'll call intellectual discussions about experiments and designs and things [with the astronauts]. I have some ideas for even some contemporary NASA research. In fact, they are truly doing some research based upon an idea I proposed. That really made me feel good, because I realized that even in the engineering aspects, I could play with them. Participate like I'm their equal, if you know what I mean.

Simonyi: Experienced people just do so much better in space than rookies.

In October, Simonyi exercised his $5 million option to buy a return ticket to the ISS. He is scheduled to fly this spring. TR

ADAM FISHER WRITES ABOUT SCIENCE AND TRAVEL. HIS WORK HAS APPEARED IN THE *NEW YORK TIMES MAGAZINE*, *NEW YORK*, AND *WIRED*.

REVIEWS

MUSIC

Bootleg Battle Lines

RIVAL AESTHETICS IN THE MASHUP COMMUNITY.

By LARRY HARDESTY

Five minutes into Girl Talk's October concert at the Starlight Ballroom in Philadelphia, about a hundred audience members have crowded onto the stage and are dancing as a dry-ice haze seethes around them, strobed by colored lights. Girl Talk himself—a.k.a. Gregg Gillis, a 27-year-old former biomedical engineer from Pittsburgh—bends over a laptop on a table at the front of the stage, a white bandanna around his head. About 15 minutes in, a shirtless young man leaps onto the table. His furious dancing loosens a cable plugged into Gillis's laptop, and the music booming through the club's P.A. speakers abruptly stops. "The people dancing on the table are not helping anyone," Gillis says into his microphone, as he fumbles with the cables taped to the floor. Booing from the audience finally shames the accidental saboteur off the stage.

GIRL TALK CONCERT
October 9, Starlight Ballroom, Philadelphia

FEED THE ANIMALS
Girl Talk
Album available on illegalart.net

DJ EARWORM MASHUPS
djearworm.com

Such are the perils of live performance in the age of the mashup, a fledgling art form that, like Gillis's shows, blurs the boundary between creator and consumer. A mashup is a digital recombination of musical elements extracted from different recordings—say, a vocal line from one song, a piano part from another, a drum pattern from a third. Some observers trace the form's origins to avant-garde experiments with tape loops in the 1970s, others to the "sampling" of existing recordings in 1980s rap. But the mashup is a distinctly 21st-century phenomenon, made possible by the proliferation of digital music files and the increasing quality and accessibility of software for manipulating them.

Gillis may be the most popular mashup artist in the United States. He's opened for Beck. He's performed at the rock festival Lollapalooza. His MySpace page gets more hits than that of indie-rock sensation Wilco. When he tours, he packs good-sized clubs—like the Starlight Ballroom, where more than a thousand people pressed toward the stage, dancing.

Part of Gillis's appeal is the sheer number of samples he combines in his mashups. Wikipedia lists 24 sources for "Play Your Part (Pt. 1)," the first track on his latest album, *Feed the Animals*. "Play Your Part" begins with a vocal by the hip-hop group UGK, paired with an instrumental track from the Spencer Davis Group's "Gimme Some Lovin'." About 42 seconds in, the rhythmic chant "Pump that shit up," from a song of the same title, succeeds the UGK lyric, and a few seconds later, "Gimme Some Lovin'" drops out. The looped fragment "Pump that shit" continues over a drum sample from a song by the Louisiana R&B singer Cupid. The vocal drops out, but the drum beat continues as the signature synthesizer arpeggios of Pete Townshend's "Let My Love Open the Door" enter. New samples succeed each other for another three and a half minutes, taking in the work of rappers Ludacris, Birdman, and T.I. and the bands Twisted Sister, Rage Against the Machine, and Temple of the Dog—among others.

A good mashup can revivify the familiar by placing it in a new context, and for the crowd in Philadelphia, that's what Girl Talk's work appeared to do. Cheers went up when recognizable instrumental lines entered the mix. Audience members sang along with sampled hip-hop lyrics and danced with an enthusiasm that the source songs probably wouldn't have inspired on their own.

But among Gillis's fellow mashup artists, the response has been tepid. "The stuff he's putting over the top of a track seems to be like, 'Oh, remember this tune, remember this tune, remember this tune,'" says Tim Baker, who hosts a music-themed podcast called Radio Clash. "It's like you're trying to watch TV, and someone is sitting there switching the channel every 30 seconds."

"Form requires repetition," says Jordan Roseman, who makes mashups under the sobriquet DJ Earworm. "You listen to any pop song on the radio: the elements repeat themselves. They go away, you miss them, they come back, and you welcome them. And just when you're getting sick of them, it goes somewhere else. And just when you start to miss them again, they come back." Girl Talk, however, simply discards each of his samples after it's played for 30 or 40 seconds.

MONSTER MASH Gregg Gillis is the mashup artist known as Girl Talk. His concerts, like this one at Northeastern University, are nuts.

JASON BERGMAN/RETNA LTD

He also tends to pair instrumental tracks with hip-hop vocals, as the analysis of "Play Your Part (Pt. 1)" might suggest. "In the mashup community," says Luke Enlow, a mashup artist from New Hampshire who releases music under the name Lenlow, "that's kind of seen as a cop-out because it's very easy to do, because you don't have to worry about keys matching."

Gillis doesn't deny that hip-hop mashups are easier to do; he just considers that irrelevant. "What the Ramones play isn't very difficult to play," he says, referring to the New York band widely credited with launching the punk-rock movement. "I think of playing the computer as a very punk exercise." He also invokes the figure of Joe Satriani, a rock guitarist renowned for his blisteringly fast solos. "Joe Satriani is not necessarily more important than [Nirvana's] Kurt Cobain just because he can wail on the guitar better," Gillis says.

It's a common pattern in music history, however, that at the moment of a popular form's ascendancy, its most ambitious practitioners begin to move in a more esoteric direction. The sidemen who played in Benny Goodman's small ensembles at the height of swing are one example; the Beatles and Beach Boys in the mid-1960s are another. Mashups haven't yet achieved the type of cultural prominence that jazz and rock did in their heyday, but if there's a similar transitional figure in the current mashup scene, it could well be Roseman.

Roseman double-majored in music and computer science at the University of Illinois, and because he can analyze the harmonies in his raw materials, he can see key clashes looming a mile away. He doesn't have to rely as heavily as his peers do on trial and error to find samples that fit together musically.

He's also more skilled than many at acquiring raw material in the first place. The digital files from which mashups are made are rarely complete recordings; they're usually isolated vocal or instrumental tracks. Recently, it's become more common for recording artists themselves to release disaggregated tracks to encourage mashup artists to remix them. Sometimes record labels will leak the tracks unofficially, to drum up publicity. Sometimes engineers spirit raw tracks out of the studio: once they're posted online, they rapidly propagate through the mashup community. Disaggregated tracks can also be found in surround-sound recordings and video game software. But if no such option is available, mashup artists have to try to extract the material they need from complete recordings.

Roseman wrote a book, *Audio Mashup Construction Kit*, that has a 40-page chapter called "Unmixing," about isolating vocals and instrumentals. One of the tricks he describes is to find a section of a song where an accompaniment figure repeats for a few bars before a vocal comes in. Software can then, effectively, subtract the repeated figure from the final mix, isolating the vocal line.

It's Roseman's artistic instincts, however, that set him apart. Like Girl Talk's mashups, Roseman's generally sample multiple songs: his biggest hit, "United State of Pop," bor-

rows elements from all of Billboard's top 25 songs from 2007. But rather than string his samples together in long chains, as Gillis does, Roseman gradually layers them over each other, adding texture and building momentum as a song progresses.

A good example is the hypnotic "Stairway to Bootleg Heaven," which borrows tracks from seven different recordings. The heart of the mashup is the juxtaposition of an '80s Eurythmics song and a cover of Led Zeppelin's "Stairway to Heaven" by, of all people, Dolly Parton. On its own, the unlikely and surprisingly effective pairing of synthesized rhythm section with fiddle and mandolin would be enough for a memorable mashup. But Roseman goes further, adding a minute-and-a-half introduction that combines a piece by performance artist Laurie Anderson with a song by the synth-pop band Art of Noise. Toward the end of the mashup, a sample from the Beastie Boys' "So What'cha Want" adds urgency, and at the song's climax, Pat Benatar's "Love Is a Battlefield" enters in double time. Throughout the mashup, as a kind of connective tissue, a sample from the Beatles' "Because" floats in and out, spectral and mysterious. Although several of the recordings Roseman samples sound dated if not risible on their own, the combination is sublime.

Roseman hasn't enjoyed nearly the popular success that Gillis has (though his work is by no means obscure: "United State of Pop" was one of the 100 most-played songs on pop radio for several months in 2008, and his remarkable mashup of Kanye West's "Love Lockdown" and Radiohead's "Reckoner" met the approval of West himself, who posted the accompanying video on his website). Still, if the question is whose mashups we'll be listening to 20 years from now, I know who I'd put my money on. TR

LARRY HARDESTY IS A *TECHNOLOGY REVIEW* SENIOR EDITOR.

WWW Create your own mashup: **www.technologyreview.com/mashups**

IDENTIFICATION

RFID's Security Problem

U.S. PASSPORT CARDS AND NEW STATE DRIVER'S LICENSES USE RADIO FREQUENCY IDENTIFICATION. THE TECHNOLOGY MAKES IDENTIFYING TRAVELERS EASY, BUT IS IT SECURE ENOUGH?

By ERICA NAONE

Starting this summer, Americans will need passports to travel to Canada, Mexico, Bermuda, and the Caribbean—unless they have passport cards or one of the enhanced driver's licenses that the states of Washington and New York have begun to issue.

Valid only for trips by land and sea, these new forms of identification are a convenient, inexpensive option for people who don't need to travel by plane. U.S. passport cards, which were introduced in July, cost about half as much as a full passport, and the extra cost of getting an enhanced driver's license rather than a regular one is even lower. Enhanced licenses have been available in Washington since January 2008 and in New York since September; other border states, including Michigan, Vermont, and Arizona, intend to offer them as well.

NEW YORK ENHANCED DRIVER'S LICENSE
$30 fee, added to the cost of a driver's license
www.nydmv.state.ny.us/edl-main.htm

WASHINGTON STATE ENHANCED DRIVER'S LICENSE
$15 fee, added to the cost of a driver's license
www.dol.wa.gov/about/news/priorities/edl.html

U.S. PASSPORT CARDS
$45
travel.state.gov/passport/ppt_card/ppt_card_3926.html

But not everyone is convinced that the new IDs are a good idea. The passport card and the enhanced licenses contain radio frequency identification (RFID) tags, which are microchips fitted with antennas. An RFID reader can radio a query to the tag, causing it to return the data it contains—in this case, an identification number that lets customs agents retrieve information about the cardholder from a government database. The idea is that instant access to biographical data, a photo, and the results of terrorist and criminal background checks will help agents move people through the border efficiently. RFID technology, however, has been raising privacy concerns since it was introduced in product labels in the early 2000s.

Meanwhile, although experts say that some RFID technologies are quite secure, a University of Virginia security researcher's analysis of the NXP Mifare Classic *(see Hack, November/December 2008)*, an RFID chip used in fare cards for the public-transit systems of Boston, London, and other cities, has shown that the security of smart cards can't be taken for granted. "I think we are in the growing-pains phase," says Johns Hopkins University computer science professor Avi Rubin, a security and privacy researcher. "This happens with a lot of technologies when they are first developed."

BORDERLINE SECURITY

The first of the new ID cards to be introduced, the federal passport cards and the Washington driver's licenses use similar technology, which has been reviewed and approved by the U.S. Department of Homeland Security. The cards' RFID devices, called electronic product code (EPC) tags, are much like bar codes. The tags are inexpensive and can, in ideal conditions, be read from about 150 feet away—an unusually long range for RFID, says Ari Juels, director and chief scientist at RSA Laboratories in Bedford, MA, which collaborated with researchers from the University of Washington to evaluate both cards.

Although the cards don't store personal information, the researchers concluded that even storing a unique number raises some

privacy concerns. "If you think about the Social Security number, at some point there could have been an argument that it's just a number, not personal information," says Tadayoshi Kohno, an assistant professor of computer science at the University of Washington, who participated in the study. "But numbers evolve over time, and uses evolve over time, and eventually these things can reveal more information than we initially expect." What's more, relatively common RFID readers, such as those used for inventory control, could under some circumstances read the cards' numbers from quite a distance. The researchers felt there was a risk that the cards could be used to track people, the way a few shopping centers in Britain have used signals from cell phones to track customers' shopping habits and monitor how long they stay in stores. Although people carry other cards and devices that could also be used for tracking, the researchers note that the identification cards can be read at longer range than many other RFID tags and that people are likely to carry them at all times, while they might leave, say, their cell phones at home. And regular U.S. passports, which also contain RFID chips, use technology that makes privacy problems less likely. Passports, unlike passport cards, must be read from up close, and they have a security system that requires an official to optically scan characters from the document in order to gain access to the personal data stored in the chip.

Gigi Zenk, a spokesperson for the Washington State Department of Licensing, says that Washington has made it illegal for third parties to use data from RFID tags without the tag owners' consent. She and other officials add that anyone concerned about privacy can use the privacy sleeves provided with the cards, which are designed to block radio signals so that the cards are harder to read surreptitiously. But the Washington study showed that the sleeves didn't always work: they didn't block radio signals when crumpled, for instance. The researchers also argued that most people are unlikely to use the sleeves, anyway. Even some privacy researchers Juels consulted confessed to having lost them, he says.

And privacy isn't the only issue here: the researchers say that unauthorized reading would threaten border security as well. If it's easy to get the identification number out of the cards, then it's relatively easy to counterfeit them, simply by loading a stolen ID number onto a blank, off-the-shelf chip. If each RFID chip also had a unique, hardwired serial number, which had to correspond to the stored ID number, it would be harder to counterfeit. But neither the Washington licenses nor the passport cards have that extra security feature.

HARRY CAMPBELL

The Washington cards are open to one additional type of attack: EPC tags can be disabled when a reader issues a "kill" command. Although each tag is designed to be protected by a PIN that allows only authorized users to issue the command, the state never set the PIN on the cards it distributed, allowing anyone with an RFID reader to set it himself and commence killing cards. If a good number of Washingtonians with enhanced licenses were gathered at a border crossing, someone could cause a disruption by killing large numbers of cards. An attacker could also use this tactic to harass particular individuals, since a killed card is likely to draw suspicion.

Juels is quick to note that the cards won't be the only thing protecting the border. "If border agents do all that they're supposed to do [including, for example, comparing the photographs stored in the database with those printed on the ID], they should be able to detect counterfeits," he says. He adds, however, that it's human nature to become less vigilant when there's technology to lean on.

When I asked the Department of Homeland Security about these concerns, press secretary Laura Keehner responded with a statement that said, in part, "While the risks described in the University of Washington/RSA paper may be technically possible, we believe that many are improbable, and even if realized, would have little impact other than causing an individual traveler minor inconvenience at the border. ... As we identify additional mitigation strategies, we will continue to strengthen requirements for ... cross-border travel documents in order to both enhance border security and privacy of the document holder."

THE NEW YORK LICENSE, AND BEYOND

No independent researcher has yet published an evaluation of New York's enhanced driver's license, but the card avoids some of the concerns raised about the federal and Washington cards. The chips in the New York licenses have serial numbers to protect them against counterfeiting, and their memory banks have been locked to protect them against unauthorized use of commands. It's

admirable that Homeland Security and the states it's working with are willing to make use of better technologies than they chose at first. But it's not clear whether these efforts will go far enough.

The New York licenses present the same privacy issues that the other cards do, and as Keehner's comments suggest, officials have a tendency to dismiss such concerns—which could very well mean that nothing will be done about them. Yet surely it's possible to protect the privacy of cardholders without requiring them to keep track of privacy sleeves. For example, says Avi Rubin, each card could be fitted with a button that allows the user to control when to send information. Unless the button was pushed in, the ID wouldn't respond to queries. Such cards would cost a bit more, but they could offer more security as well as more privacy.

As long as the remaining problems are ignored, though, it's unlikely that the technology will become good enough to protect international borders without compromising the privacy of thousands or millions of people. Tadayoshi Kohno, for one, says that at this point, he is not convinced that RFID even offers security advantages over the old IDs. Technology used on this scale, and for purposes this important, should be clearly better than what it's replacing: the U.S. experience with electronic voting systems shows what can happen when it's not. If officials continue to advocate band-aids such as privacy sleeves rather than working to address the full extent of critics' concerns, they will ultimately undermine the very technology that they hope to promote. While new ID technology seems likely to stay, it could become a fiasco if officials don't pay attention to the work of hackers and security researchers. These people try to expose weaknesses before they can be exploited maliciously. It's much less painful to swallow the news from them than to wait until a problem becomes embarrassing—or devastating. TR

ERICA NAONE IS A *TECHNOLOGY REVIEW* ASSISTANT EDITOR.

ARCHAEOGENETICS

Our Past Within Us

A NEW FIELD IS ILLUMINATING PREHISTORY.

By MARK WILLIAMS

How did we become the thinking animals that we are? That's the question at the heart of the study of human prehistory—and the one that Colin Renfrew has been asking since the summer of 1962, when he travelled to Milos, one of the Cycladic Islands in the Aegean Sea, a source of the black obsidian that was the earliest commodity traded by humans.

Renfrew—Lord Renfrew of Kaimsthorn since he was made a British life peer in 1991 to honor his many contributions to archaeology—was then a graduate student at Cambridge. As an undergraduate, he'd first studied natural sciences before moving on to archaeology; thus, seeking a means to determine the provenance of the obsidian that prehistoric peoples favored for toolmaking, he tried the novel tactic of using optical emission spectroscopy to analyze its trace elements.

PREHISTORY: THE MAKING OF THE HUMAN MIND
By Colin Renfrew
Modern Library, 2008, $23.00

"We really hit lucky," Renfrew told me recently. "Obsidian makes much thinner, sharper blades than flint and so was a preferred substance found at almost all the early Neolithic sites in Greece. In fact, we learned it was already traded during the Upper Paleolithic." Yet the only potential quarries for obsidian in the Aegean were on Milos. "So the material documents the earliest known seafaring," Renfrew says. "We needed nevertheless to be sure where it was coming from. Trace-element analysis let us characterize each different obsidian source, since they're created by relatively recent volcanoes and tend to be consistently distinguishable." Renfrew found that he could clearly graph how far the material had traveled: obsidian from a site in Anatolia (modern Turkey), in one instance, had been transported approximately 500 miles to Palestine. Overall, the picture that emerged suggested a world where most people never traveled more than a few miles from where they were born, but a few went everywhere. "It's an interesting picture," Renfrew says. "It was the seafarers who traveled distances, getting around the Aegean Islands quite widely and clearly doing that before the origins of farming."

Next, Renfrew turned his attention to what had been a cherished assumption in archaeology: that prehistoric cultural innovation originated in the Near East and diffused to Europe. "Just in archaeological terms, I didn't think that argument was very good," he says. "In Bulgaria and Romania, I'd been struck by the early metallurgy at some sites. So when radiocarbon dating arrived—particularly when tree-ring calibration came through in the late 1960s—the penny dropped." The new technological methods proved that, indeed, certain artifacts in Central and Western Europe were older than their supposed Near Eastern forerunners. Renfrew wrote a book, *Before Civilization: The Radiocarbon Revolution and Prehistoric Europe* (1973), pointing out that "the previous diffusionist chronology collapsed at several points."

Over the decades, Renfrew has remained at his field's cutting edge; he was among the earliest advocates of technologies like computer modeling and positron emission tomography (PET), the latter to examine contemporary subjects' brain activities as they replicated the toolmaking of Lower Paleolithic hominids. In his latest book, *Prehistory: The Making of the Human Mind*, Renfrew has not only produced a summary of by far the vaster part of human history but also provided an account of archaeology's advance since European scholars real-

ized some 150 years ago that the human past extended many millennia further back than 4004 B.C.E. (the 17th-century theologian Bishop Ussher's estimate of when God had created the world). Given its vast subject and its strictures of length, probably the only real criticism one can make of the book is that in its index, under the letter *R*, the author is missing. It's a significant omission: Renfrew has informed today's understanding of human prehistory much as he says Gordon Childe—who is responsible for the concepts of the Neolithic and urban revolutions—shaped thinking during the first half of the 20th century. Like Childe, he has been one of the great archaeological synthesizers, working to construct a theory of global human development. For Renfrew, all archaeology ultimately leads to cognitive archaeology—the branch that investigates the development of human cognition.

In particular, Renfrew has been preoccupied by what he has dubbed the "sapient paradox": the immense time lag between the emergence of anatomically modern human beings and the advent of the cultural behaviors that we take to define humanity.

Prehistory is defined as that period of human history during which people either hadn't yet achieved literacy—our basic information storage technology—or left behind no written records. Thus, in Egypt, prehistory ended around 3000 B.C.E., in the Early Dynastic Period, when hieroglyph-inscribed monuments, clay tablets, and papyrus appeared; in Papua New Guinea, conversely, it ended as recently as the end of the last century. Archaeologists and anthropologists accept this region-by-region definition of prehistory's conclusion, but they agree less about its beginning. A few have seen prehistory as commencing as recently as around 40,000 B.C.E., with the emergence of Cro-Magnon man, who as *Homo sapiens sapiens* was almost indistinguishable from us (although Cro-Magnons, on average, had larger brains and more robust physiologies). However, most experts would probably say that prehistory began in the Middle Pleisto-

BETTMANN/CORBIS

MYSTERY MAN Cro-Magnons emerged about 40,000 years ago and were very similar to us. So why did it take tens of thousands of years for civilization to take hold?

cene, as many as 200,000 years ago—when *Homo neanderthalensis* (sometimes classified as *Homo sapiens neanderthalensis*) and archaic *Homo sapiens* emerged. Either way, it's assumed that the appearance of *Homo sapiens sapiens* triggered "a new pace of change ... that set cultural development upon [an] ... accelerating path of development," as Renfrew writes in *Prehistory*. But Renfrew thinks that this acceleration must have been due to something else.

"The evidence that *Homo sapiens*' arrival equates with full linguistic abilities, the human behavioral revolution, and so on is very limited," Renfrew told me, adding that he sees nothing clearly separating the flint tools of the Neanderthals from those associated with *Homo sapiens*. As for the cave paintings at Altamira, Lascaux, and other Southern European sites, which are 15,000 to 17,000 years old: "They're amazing, but stylistically singular and very restricted in their distribution. They mightn't be characteristic of early *Homo sapiens*." Overall, Renfrew thinks, if aliens from space had compared *Homo sapiens* hunter-gatherers with their earlier counterparts, they probably wouldn't have seen much difference.

Two and a half million years ago, the first protohumans, *Homo habilis*, shaped stones to take the place of the claws and fangs they lacked, using them to kill small animals and scavenge the remains of larger ones. The payoff was immense: whereas metabolic needs like food processing constrain brain size for most mammals, eating meat enabled *habilis* to start evolving a smaller gut, freeing that metabolic energy for the brain's use. After a few hundred thousand years, later hominids like *erectus* and *ergaster* had developed straightened finger bones, stronger thumbs, and longer legs. The expansion of hominid brains—they were twice as big within a million years, three times by the Middle Paleolithic—enabled symbolic communication and abstract thought. By 50,000 B.C.E., our ancestors had spread from Africa through Asia, Europe, and Australia.

ARCHAEOGENETICS EMERGES

The paradox, or puzzle, is this: if archaic *Homo sapiens* emerged as long as 200,000 years ago, why did our species need so many millennia before its transition, 12,000 to 10,000 years ago, from the hunter-gatherer nomadism that characterized all previous hominids to permanent, year-round settlement, which then allowed the elaboration of humankind's cultural efforts? To answer this question, Renfrew calls for a grand synthesis of three approaches: scientific archaeology, which collects hard data through radiocarbon dating and similar technologies; linguistic study aimed at constructing clear histories of the world's languages; and molecular genetic analysis.

Renfrew sees this last approach, which he calls archaeogenetics, as progressing most rapidly. So far, archaeogenetics has relied principally on analysis of human mitochondrial DNA (mtDNA), which is found not in the paired chromosomes within cell nuclei but in tiny loops, called plasmids, inside the mitochondria that generate most of the cell's chemical energy. Unlike chromosomal DNA, mtDNA derives only from the ovum—so it represents only the maternal lineage—and does not recombine from generation to generation. Thus, it's essentially static. Yet over thousands of years, single-nucleotide poly-

morphisms—mutations that alter a single DNA base pair—do occur in mitochondria at a statistically predictable rate. Given that mutation rate, modern researchers can analyze and compare mtDNA samples from individuals throughout the world, using the similarities and differences to construct a great human family tree.

Furthermore, Renfrew told me, "studies of mtDNA mutation rates give an approximate chronology that ties quite nicely to data from radiocarbon dating of fossil remains." Like radiocarbon dating itself, mtDNA analysis has refuted long-cherished myths about race by showing that humankind almost certainly had a single origin in Africa, with our main dispersal out of that continent occurring about 60,000 years ago and probably involving a relatively small number of humans. During humanity's global diaspora, many populations grew isolated. Today, mitochondrial haplogroups—groups that share common ancestors—are identifiable as originating in Africa, Europe, Asia, the Americas, and the Pacific Islands.

Mitochondrial-DNA analysis is only one tool in an expanding genomic arsenal. The fuller picture is, perhaps, even more dramatic than Renfrew suggests. Increasingly, we look like just one taxonomic variant within the continuum of the hominid clade: a *FOXP2* gene variant strongly implicated in our language capabilities, for instance, is one we shared with Neanderthals 60,000 to 100,000 years ago. According to John Hawks, an anthropologist and population geneticist at the University of Wisconsin–Madison, Neanderthals and *Homo sapiens* may well have interbred: "No primate species have established reproductive boundaries into sterility in less than a couple of million years. Neanderthals and ourselves resemble, maybe, chimps and bonobos, which are geographically separated in nature but hybridize freely if placed together in a zoo." In short, though we tend to be species-centric about the concept of humanity, the reality is that all organisms are temporary receptacles into which DNA pours itself, and interspecies boundaries are more fluid and tenuous than we've thought. In a sense, the idea of *Homo sapiens* as a distinct species is one more racial myth.

Other assumptions don't hold up any better. Not only did Cro-Magnons have larger brains than we do, for example, but the difference was big. "In the last 10,000 years, our brains have shrunk about 200 cubic centimeters," Hawks explains. "If we shrunk another 200, we'd be the equivalent of *Homo erectus*. One possibility is this represents greater efficiency—our brains using less energy, needing less developmental time, and signaling faster. Alternatively, of course, we're getting dumber."

Pondering these and similar questions, Hawks and other researchers wondered if data from the International HapMap Project—a consortium established to catalogue the patterns of human genetic variation in different populations around the globe—could help clarify matters.

In population genetics, "linkage disequilibrium" means that certain alleles—the alternative versions of a given gene responsible for variations such as brown or blue eyes—occur together more frequently than can be explained by chance. It is a sign that evolutionary selection has been working: advantageous new mutations are appearing. Hawks and his colleagues applied novel genome-scanning approaches to HapMap data to track linkage disequilibrium and then, in December 2007, published a controversial paper, "Recent Acceleration of Human Adaptive Evolution," in the *Proceedings of the National Academy of Sciences*.

"When I was in graduate school in the mid-'90s, the dogma was that culture had halted evolution," Hawks told me. But he and his colleagues found genomic evidence that, on the contrary, culture has increased the pace of human evolution over the last 40,000 years, and especially over the last 10,000. What's driven this acceleration, they argued in *PNAS*, is the global human population explosion that commenced 10,000 years ago, as a consequence of the agricultural revolution. Humankind invented agriculture, started eating different foods, and began dwelling in cities; populations expanded, allowing large numbers of mutations. Natural selection promoted the spread of beneficial variations.

According to Hawks, evidence indicates recent selection on more than 1,800 human genes. Beyond identifying a selected allele, he adds, analysis can often determine from its sequence something of what the allele does. Hawks believes that some of the new alleles confer new digestive capabilities, as with glucose and lactose tolerance; pathogen resistance, as against malaria; improved capacity for DNA repair, which may be associated with human longevity; and new neurotransmitter variations, like the dopamine variant DRD4-7R, which was strongly selected for in some populations perhaps 40,000 years ago and is implicated in heightened tendencies toward impulsiveness, attention deficit disorder, and alcoholism. (More-conservative population geneticists argue that while humans are probably still evolving, it's not clear that evolution is accelerating, and still less certain which alleles are of recent origin.)

Discussing differences in populations isn't something our egalitarian society enjoys. But one of Hawks's coauthors, Henry Harpending, a population geneticist and anthropologist at the University of Utah, thinks it should be: "Citizens should appreciate that evolution is ongoing, numerous real human differences exist, and we're hurting many people by denying them." Harpending notes, too, that life-sciences industries followed up on the paper, seeking opportunities for drug development and personalized medicine. "In the face of embarrassed silence from the world's scientists, they're not inhibited," he says. "They want to make money and are on it like crows on roadkill." If Harpending is right, we will learn new facts about human development whether we want to or not. TR

MARK WILLIAMS IS A CONTRIBUTING EDITOR TO *TECHNOLOGY REVIEW*.

A MICROPROCESSOR

Before the iPill is swallowed, a doctor loads it with a program that instructs it where to deliver its contents. The microprocessor monitors the pill's location, using data on pH, temperature, and the time elapsed since ingestion, and then determines when and in what pattern the pill's fluid pump will release drugs into the patient's digestive tract.

B pH SENSOR

The pH sensor helps the pill track its passage from the highly acidic stomach to the less acidic intestines. The pill's environment grows progressively more alkaline until it reaches the colon, which is more acidic again.

Philips iPill

A TINY DEVICE DELIVERS DRUGS EXACTLY WHERE THEY'RE NEEDED IN THE GUT.

By ERICA NAONE

ELECTRONIC PILLS have been used for diagnostic applications such as imaging, but the iPill from Philips Research, designed to treat gastrointestinal disorders, goes a step further, dispensing medication at a location and rate programmed by a physician. The disposable capsule, which is about the same size as an ordinary pill, contains a tiny computer, a wireless transmitter, and a series of sensors; it passes naturally through the digestive system after being swallowed with food or water. Although the iPill is still a prototype, Philips is about to begin testing it in animals and is working with pharmaceutical companies to evaluate what drugs might work best with it.

C TEMPERATURE SENSOR

When the patient swallows the iPill, the temperature sensor detects the change from room temperature to body temperature. That causes the microprocessor to start the clock that will help the pill calculate its location.

COURTESY OF PHILIPS

D FLUID PUMP

The drugs stored in the pill's reservoir can be released in a single burst, in a series of doses at multiple locations, or little by little as the capsule travels through the gut. The pump that releases the drugs consists of a motor and a piston driven by a screw rod, which can move precise amounts of fluid at the command of the microprocessor.

E WIRELESS TRANSCEIVER

The iPill can communicate by radio frequency with a control device outside the body. It can gather temperature data, for example, and report on changes it finds as it travels. If a drug is causing a bad reaction, a doctor can send a command to stop the pill from releasing any more of it.

F BATTERY

The iPill is powered by a silver oxide battery that holds a charge intended to last 48 hours—about twice the duration of the pill's natural transit through the body.

Spinning Silk into Sensors

A SIMPLE PROCESS TURNS COCOONS INTO OPTICAL DEVICES WITH BIOLOGICAL APPLICATIONS.

By KATHERINE BOURZAC

1

Silkworm cocoons shipped by the boxful from Japan to an optics lab at Tufts University will meet a different fate from those headed to textile factories around the world. Rather than being woven into curtains or clothing, the strong protein fibers that caterpillars once spun around themselves will be used to build optical materials that can serve as the basis for sensors and other devices. Bioengineer Fiorenzo Omenetto, who creates the devices, ultimately hopes to build implantable, biodegradable sensors that could help monitor patients' progress after surgery or track chronic diseases such as diabetes.

Omenetto realized that silk was good for more than shirts and ties, he says, when he got to talking with David Kaplan, the head of Tufts's biomedical-engineering department, with whom he shares a hallway. Kaplan turns silk proteins into cell-friendly scaffolds for engineering biological tissues, including corneal implants. The strongest natural fiber known, silk is favored by tissue engineers because it's mechanically tough but degrades harmlessly inside the body.

Trained as a physicist, Omenetto figured that if silk made good artificial corneas, it might also make good optical devices. As it turns out, he says, the silk devices he's making work as well as those made from traditional optical materials like glass and plastic—in some cases, even better. And unlike those materials, silk doesn't need to be processed at high temperatures or with harsh chemicals.

That's one reason that silk is so well suited for use in biosensors: because silk devices can be manufactured in a gentle environment, it's possible to incorporate additional biological molecules (such as proteins) into them as they are being built. These molecules serve as sensors that, once integrated into the silk devices, can remain active for years. In the devices that Omenetto and Kaplan are developing, proteins embedded in the optical material efficiently bind to a target such as oxygen or a bacterial protein; when they do, the light transmitted by the sensor changes color.

PORTER GIFFORD

Left: Fiorenzo Omenetto on the steps of the Tufts bioengineering building, where he makes silk optical devices.
1. Researcher Carmen Preda scoops up silkworm cocoons, the starting material for the biodegradable devices. The cocoons must be cut open and the dead worms inside them discarded.
2. Preda stirs cut-up cocoons in a salt solution. The cocoons are boiled in a beaker over a hot plate to dissolve the protein that holds them together, sericin. The silk fibers, now pure fibroin protein, will be dissolved in another salt solution.
3. Using a syringe, Preda loads the syrupy silk solution into a dialysis cartridge. The cartridge will be placed in a beaker of water, which will draw the salt out through the cartridge's clear window. Finally, Preda will use a syringe to suck out the pure water-fibroin solution left behind, which she'll store in the fridge.

OPTICAL RECIPE

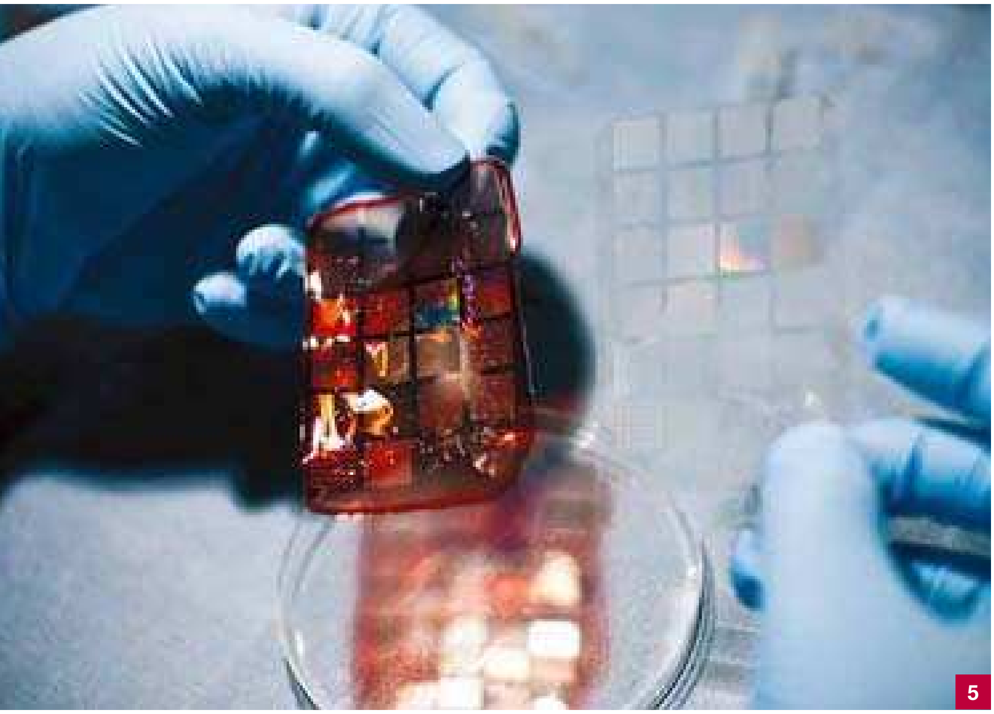
Omenetto's recipe begins with cocoons spun by the silkworm *Bombyx mori*. First, he says, "you cut the cocoon and remove the worm—much to the chagrin of vegans." Senior research technician Carmen Preda then boils the cocoons in a solution containing the salt sodium carbonate. This helps dissolve sericin, a gluey glycoprotein that holds the cocoons together but causes immune reactions in humans. After the silk fibers dry, they're dissolved in a solution of lithium bromide. When it cools, Preda uses a syringe to load it into a dialysis cartridge. She sets this inside a beaker of water, which draws out the salt.

What's left in the cartridge is a clear, viscous solution of the purified protein silk fibroin. Preda removes this silk "syrup" from the cartridge with a syringe and loads it into a row of test tubes; this is the starting material for Omenetto's optical components. If he wants to use the components in a biosensor, he can add a protein targeting a particular molecule—say, oxygen-binding hemoglobin—at this stage. "You have this nice water-based solution that you can mix anything into," Omenetto says.

Hemoglobin is a relatively stable protein, but the silk materials can also preserve the activity of less resilient proteins, such as enzymes. As a test case, the Tufts researchers have made silk structures containing a volatile horseradish enzyme called peroxidase; glucose sensors might incorporate hexokinase, an enzyme that binds to the sugar.

The molds used to shape the silk-protein solution into optical devices are patterned with nanoscale features. Such fine detailing is important in optics, since light interacts best with features at a scale no bigger than its own wavelength—about 400 to 700 nanometers in the case of visible light. In the ambient light of the lab, the plastic molds' nanopatterned regions shine softly, like the inside of an abalone shell.

One device the researchers have made is a hologram, demonstrating that silk



4. To make a hologram, a researcher deposits the water-based solution of pure silk fibroin onto a mold with a pipette. Fibroin makes a good optical material because it's translucent when it dries, and it conforms well to both the nanoscale and macroscale details of molds like this one. **5.** After drying for several hours, silk optical devices like the hemoglobin-containing card in the researcher's left hand can be peeled off their molds. Each iridescent square has been molded into a different device. One is a diffraction grating that can act as an oxygen sensor.

has the same versatility as other optical materials. At the lab bench, postdoc Jason Amsden uses a pipette to deposit silk solution onto a mold etched with the Tufts logo. He leaves the mold on the counter at room temperature for about eight hours—long enough for the proteins to set into a flexible, irregular oval displaying the logo in a three-dimensional pattern of iridescent pinks and blues.

In other molds around the lab, different types of optical devices have already finished drying. Amsden selects one and gently peels it from the mold using tweezers. The device is a translucent red card impregnated with hemoglobin and patterned with several optical elements, including a diffraction grating that splits white light into its component colors.

SILK SENSORS

The card acts as a simple oxygen sensor: light passing through it changes wavelength slightly, depending on how much oxygen has bound to the embedded hemoglobin. These changes can't be seen with the naked eye but can be detected by a photodiode, a chip that turns light into electrical current. When a drop of oxygen-rich blood is placed on the sensor, for example, the hemoglobin draws in oxygen from it, and the wavelength of light registered by the photodiode shifts.

Oxygen is just one possible target for Omenetto's devices. Gratings with antibodies and enzymes embedded in them could sense just about any medically interesting molecule, be it glucose or a tumor marker. And the Tufts researchers envision not just lab sensors but implantable ones. One application Omenetto has developed will be particularly important: silk optical fibers for carrying light from the surface of the skin to the implanted sensors and back, so that it can be read by a photodetector. The sensors could be implanted during surgeries such as tumor resections and then used to monitor patients for signs of infection or recurring cancer. Omenetto and Kaplan also hope to integrate the sensors into future tissue-engineering structures that would help doctors track how well a new tissue is being incorporated into the body. The devices would dissolve harmlessly with the rest of the tissue's supportive structures.

Future sensors, Omenetto says, will have designs that lead to more dramatic color changes when the sensors bind to their targets. To create sensors that can be read with the naked eye, he drew inspiration from another insect, the morpho butterfly. Its shimmering blue color is due not to pigments but to the way light interacts with nanoscale protein pillars on its wings. Changing the pillars' structure eliminates the color. Omenetto imagines a silk-based sensor patterned with nanoscale structures that make it appear blue; a target molecule binding to proteins in the sensor would subtly change the nanostructures, making the color change or disappear. Omenetto says that the basic technologies for doing this are in place; it's simply a matter of designing the right molds. TR

WWW See how optical devices are made from silk: **technologyreview.com/demo**

FROM THE LABS

INFORMATION TECHNOLOGY

Steering Microbots

BACTERIA-BASED ROBOTS SWIM THROUGH BLOOD VESSELS

SOURCE: "FLAGELLATED BACTERIAL NANOROBOTS FOR MEDICAL INTERVENTIONS IN THE HUMAN BODY"
Sylvain Martel et al.
IEEE 2008 Biorobotics Conference, October 19–22, 2008, Scottsdale, AZ

Results: Researchers have coupled swimming bacteria to 150-nanometer-wide beads, creating tiny robots that can be steered inside blood vessels using magnetic fields controlled with a modified magnetic resonance imaging (MRI) device. The MRI can also be used to track the robots.

Why it matters: The technology could provide a new way to deliver drugs directly to tumors. The bacteria would swim through the bloodstream bearing drug-coated nanoparticles; doctors could use MRI to direct them to a specific site, such as a part of a tumor. At two micrometers in diameter, the bacteria are small enough to fit through the smallest blood vessels in the human body.

Methods: The researchers treated nanoscale polymer beads with an antibody that binds to the bacteria. The bacteria naturally contain magnetic particles and swim in different directions depending on the surrounding magnetic fields. The researchers tested their ability to steer the bacteria by altering magnetic fields around them with a special configuration of electromagnetic coils connected to an MRI. The coils, arranged at right angles to each other, allow the researchers to control the bacteria's movement in three dimensions. The researchers steered the bacteria in human blood, in rat tumors, and through glass tubes that mimic human blood vessels.

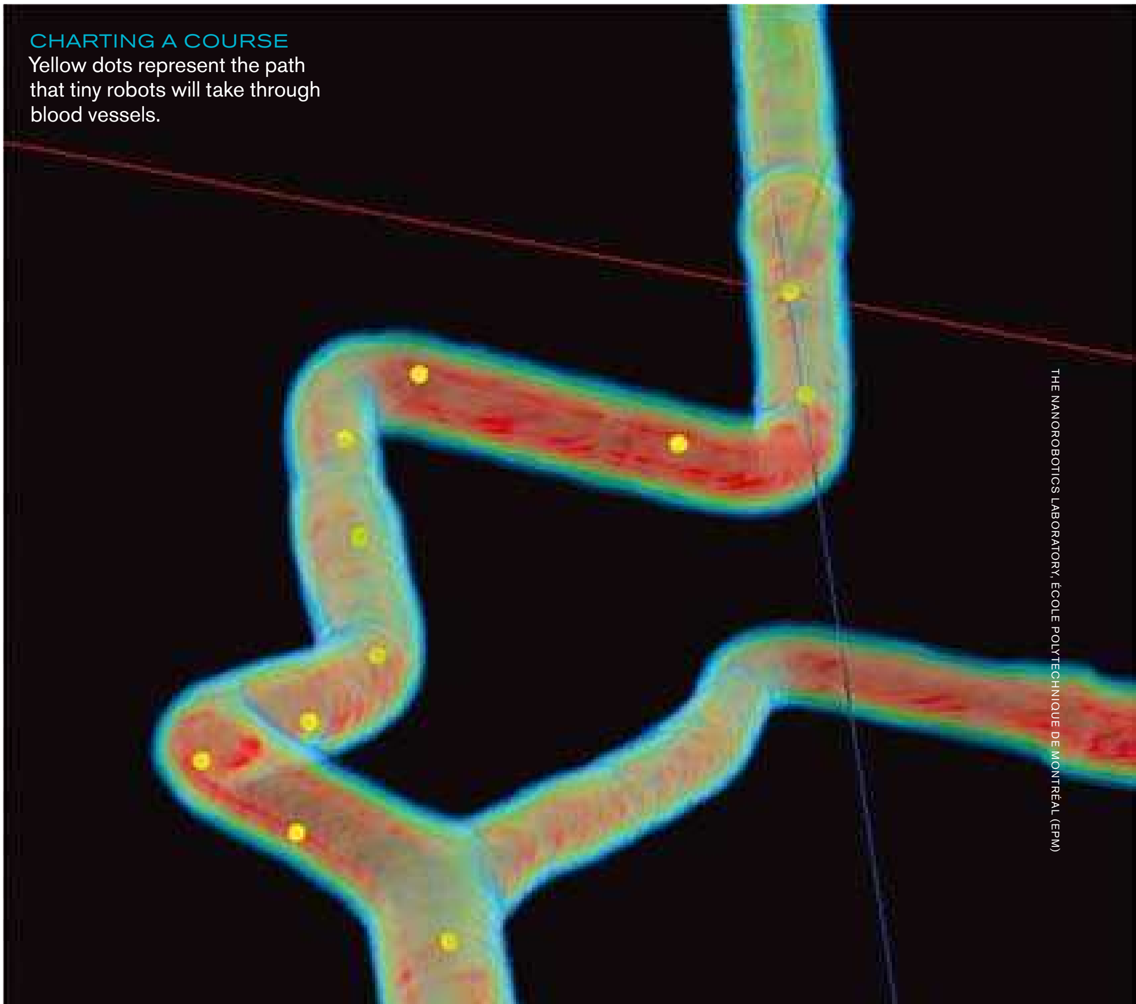
Next steps: The bacteria-propelled devices can't swim fast enough to traverse the currents in larger blood vessels. So the researchers envision ferrying the microbots through large blood vessels inside larger microparticles they have developed, whose motion can be controlled by a clinical MRI system. Those particles would release the bacteria into the small blood vessels that they are too big to enter themselves.

Plasmonic Photo-lithography

A NEW FABRICATION TECHNIQUE COULD LEAD TO SMALLER CHIPS

SOURCE: "FLYING PLASMONIC LENS IN THE NEAR FIELD FOR HIGH-SPEED NANOLITHOGRAPHY"
Xiang Zhang et al.
Nature Nanotechnology online, October 12, 2008

Results: Researchers developed, and demonstrated precise control of, a lens that converts ultraviolet light into a type of wave called a plasmon,



CHARTING A COURSE
Yellow dots represent the path that tiny robots will take through blood vessels.

THE NANOROBOTICS LABORATORY, ÉCOLE POLYTECHNIQUE DE MONTRÉAL (EPM)

which could be used to etch features as narrow as five to ten nanometers into semiconductor materials.

Why it matters: Photolithography—the technique used to manufacture microchips—is limited by the physics of conventional optical systems: it can't produce features smaller than about 30 nanometers. The new lens produces surface plasmons, which are like waves passing through electrons on the surface of a metal. Since plasmons can concentrate light energy more narrowly than conventional optics can, the plasmonic lens could carve out ultrasmall patterns, enabling higher-capacity DVDs and faster microprocessors.

Methods: The researchers created a lens that consists of concentric circles patterned onto a thin film of silver. When the circles are illuminated with an ultraviolet laser, the electrons on their surfaces oscillate at a frequency that corresponds to the circles' size, creating plasmons; the radiation produced by the plasmons extends about 100 nanometers from the lens. The researchers created a novel system that floats the plasmonic-lens arrays about 20 nanometers above a substrate. The substrate spins rapidly, creating an air flow along the bottom surface of the lenses, which regulates the nanoscale gap between the lenses and the substrate.

Next steps: So far, the researchers have used their invention to produce only relatively thick, 80-nanometer-wide lines, since they were focused on demonstrating the concept of the floating plasmonic lens. They are now conducting experiments to verify the possible resolution of the lens.

MATERIALS

Practical Plastic Solar Cells

NEW DYES AND ELECTROLYTES IMPROVE EFFICIENCY OF GRÄTZEL CELLS

SOURCE: "NEW EFFICIENCY RECORDS FOR STABLE DYE-SENSITIZED SOLAR CELLS WITH LOW-VOLATILITY AND IONIC LIQUID ELECTROLYTES"
Michael Grätzel et al.
Journal of Physical Chemistry C 112: 17046–17050

Results: Scientists at the Swiss Federal Institute of Technology and the Chinese Academy of Sciences have used nonvolatile electrolytes and a new dye to improve the stability of flexible dye-sensitized solar cells (also called Grätzel cells) while achieving efficiencies of up to 10 percent.

Why it matters: Dye-sensitized solar cells could be cheaper than conventional solar cells, because they're made of inexpensive materials and can be printed rapidly. They can also be made flexible. But they have been difficult to manufacture and unreliable to operate, because the electrolytes that carry current within them are volatile and must be carefully encapsulated. By using nonvolatile electrolytes, the researchers have made Grätzel cells that are more reliable and potentially cheaper to manufacture. What's more, the new dye allows the researchers to use the nonvolatile electrolytes while maintaining efficiencies of near 10 percent, a level necessary to compete with conventional solar cells.

Method: The researchers coupled two previously synthesized nonvolatile electrolytes with a new dye that absorbs more light. That reduced both the amount of dye required and the thickness of the solar cells, making it easier for electrical charges to move out of the cell.

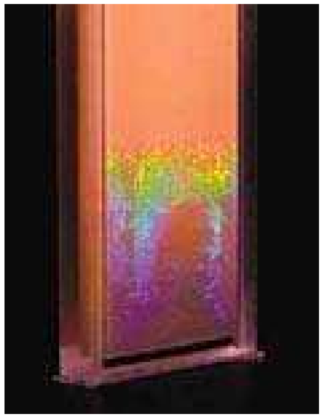
Next steps: The cells remain stable when exposed to light and high temperatures for 1,000 hours. The researchers are now testing them at higher temperatures, studying their long-term performance in a large solar panel, and working with corporate partners to commercialize the technology.

Self-Assembling Optics

NANOPARTICLES FORM SOPHISTICATED DEVICES

SOURCE: "SELF-ORGANIZED SILVER NANOPARTICLES FOR THREE-DIMENSIONAL PLASMONIC CRYSTALS"
Peidong Yang et al.
Nano Letters 8: 4033–4038

Results: Researchers at the University of California, Berkeley, led by Peidong Yang, have shown that silver nanoparticles with very regular octahedral shapes pack together under the influence of gravity to form large crystals. The crystals' optical properties can be varied by changing the amount of time the nanoparticles have to pack together, which affects the spacing between them.



PEIDONG YANG

SILVER CRYSTALS These octahedral silver nanoparticles suspended in ethanol are assembling into a large crystal. The density of the particles, which changes from top to bottom, determines what colors pass through.

Why it matters: Light striking the crystals causes the formation of what's called a plasmon, a wave passing through the electrons at the crystals' surfaces. Plasmonic crystals could be used to guide light in optical computers or to increase the sensitivity of chemical sensors. They could also serve as lenses for super-high-resolution microscopy. Using conventional lithography to etch patterns in materials can achieve a similar effect but is more expensive.

Method: Using methods that Yang developed previously, the researchers grew

silver nanoparticles in solution, then suspended them in ethanol inside a test tube. By allowing the nanoparticles to pack together for longer or shorter periods of time before evaporating the ethanol, the researchers produced densely and loosely packed crystals, whose optical properties they studied. The crystals transmitted particular bands of radiation while blocking others, and the frequency varied according to how tightly packed the crystals were.

Next steps: The Berkeley group plans to build a large plasmonic crystal on the surface of a six-inch wafer to establish that the crystals can be formed on a scale large enough for many of their potential applications.

BIOMEDICINE

Cancer Genome

COMPARING HEALTHY CELLS AND CANCER CELLS REVEALS GENETIC MISSTEPS IN CANCER

SOURCE: "DNA SEQUENCING OF A CYTOGENETICALLY NORMAL ACUTE MYELOID LEUKAEMIA GENOME"
Elaine Mardis et al.
Nature 456: 66–72

Results: Scientists from Washington University in St. Louis identified 10 genetic mutations found in the DNA of cancer cells but not in healthy cells. Both sets of cells were collected from a patient who had leukemia.

Why it matters: Previous studies that analyzed tumor DNA focused on genes thought to play a role in cancer, thus neglecting much of the genome. The new study provides an unbiased search through the entire genome, identifying genetic variants that scientists might never have noticed. The findings provide new targets for further research and drug development.

Methods: The scientists used a new sequencing technology, from San Diego–based Illumina, that is much cheaper than traditional methods. For the first time, they created full-genome sequences of both cancerous and healthy cells taken from the same person, a woman who died of acute myelogenous leukemia. By comparing the two sequences, they identified specific changes found only in the cancer cells.

Next steps: The scientists have almost finished sequencing the genome of a second patient. Because this patient is still alive and in remission, the genetic variants identified in his cancer cells may reveal clues to what makes treatment successful. The researchers are also planning to sequence genomes from different types of solid tumors.

Regrowing Nerves

BLOCKING GROWTH INHIBITORS ALLOWS ADULT NEURONS TO REGENERATE IN MICE

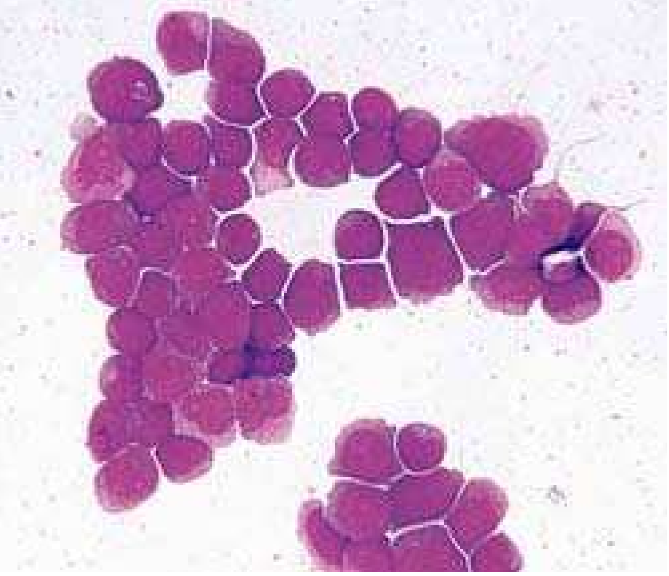
SOURCE: "PROMOTING AXON REGENERATION IN THE ADULT CNS BY MODULATION OF THE PTEN/MTOR PATHWAY"
Zhigang He et al.
Science 322: 963–966

Results: Mice with two deleted genes recovered from optic-nerve injury better than normal mice did. Up to 50 percent of their neurons survived two weeks after injury, versus about 20 percent in the control mice. Axons—the long projections in neurons that transmit signals from one cell to another—showed significant regrowth in about 10 percent of the genetically modified animals, but none in the controls.

Why it matters: Nerve cells don't normally regenerate in adults after injury, so new methods to boost their growth could spur recovery. Other research has demonstrated axon regrowth, but the magnitude of growth in this study makes it significant: some axons grew up to four millimeters in a month. Chemical inhibitors of one of the deleted genes already exist, raising the possibility that the same approach could be applied to humans.

Methods: The researchers deleted two genes, known as *Pten* and *Tsc1*, that normally inhibit neural cell growth in the brains of mice. They then crushed the optic nerve. Two weeks after the injury, the scientists tagged the crushed cells with fluorescent markers to assess cell growth and survival.

Next steps: The research group is testing the effect of deleting the same genes in mice with spinal-cord injuries. They are also developing small-molecule compounds that could mimic the deletion of *Pten* or *Tsc1* to boost axon regeneration and functional recovery in patients. TR



TIM LEY

CANCER CELLS Shown here are bone marrow cells collected from a leukemia patient. Scientists searched for cancer-related mutations by comparing the DNA in these cells and the patient's healthy skin cells.

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"Wavy Lines of Sound"

A RESEARCH PHYSICIST LOOKS TO THE PAST AND FUTURE OF RECORDED MUSIC.

By MATT MAHONEY

When George R. Harrison, then director of applied physics at MIT, surveyed the state of the art in audio recording and playback in the November 1938 issue of *Technology Review*, he was full of wonder at the progress achieved in the 60 years since Edison had introduced the phonograph. Although cheap and durable vinyl had yet to replace shellac as the recording industry's medium of choice, and all-electric record players had only recently superseded acoustic ones, Harrison confidently assured his readers that they were on the cusp of a new, "high-fidelity" era.

Grown long accustomed to the scratchy futility of the mechanical phonograph, the world is only slowly realizing the possibilities of more perfect sound reproduction. The electric phonograph and the talking motion picture as we know them are far from perfect in their re-creation of sound, but this limitation now arises from the high cost of the apparatus needed to achieve perfect results. Perfectly faithful reproducing devices should eventually be available as commonly as imperfect ones are today.

This development was nothing short of a scientific miracle, Harrison proclaimed. He went on to describe in loving detail the industrial process by which records were mass-produced:

The sight of hundreds of steam-heated presses stamping out phonograph records is likely to give rise to that exaltation which is occasionally felt on viewing one of man's accomplishments in fashioning nature to his ends. The juxtaposition of the results of art and of science seen under such circumstances may produce a peculiar emotional reaction.

Before each record press stands a young woman, at her side a flat hot plate on which rectangular slabs of dough—made from shellac mixed with clay and other materials—are kept soft and pliable. When the press opens she inserts a mass of this dough between the chromium-plated record molds which carry the replicas of the wavy lines of sound on their surfaces, closes the jaws of the press, and releases a force of over 60 tons which squeezes the mass into a thin disk, impressing on its upper and lower surfaces the sound-track grooves from the master records. A moment later a spurt of water cools the press internally, the jaws open, and the operator takes the mold from a completed disk record, ready (after its rim has been burnished) to be played. At one moment we see a mass of dough; 30 seconds later it emerges from the press transformed—the "Prelude to Lohengrin"! Not the least wonder of science is its ability to convert shellac—excreted by an insect—into a vehicle for profound emotional experience.

BIRTH OF A RECORD "At one moment we see a mass of dough; 30 seconds later it emerges from the press transformed."

Technological advances would not only increase exposure to the best in music, Harrison wrote, but also open up completely new avenues for musical participation and creation. Anticipating the karaoke machines and home recording setups of the 1970s, not to mention the remix and mashup culture of today *(see* *"Bootleg Battle Lines," p. 70*), he argued that ever-improving recording technology would change the way music was made.

There appear to be vast possibilities in the development of a new field of musical participation for the amateur, lying intermediate between listening to an expert performance, or to its reproduction, and aspiring, but less often inspiring, personal participation. …

At least one scientist with a musical bent, who possesses a home sound recorder, has gone so far as to play string quartets with himself. He first plays and records the cello part. Then he plays the resulting record through on a reproducer while he accompanies its playing with another part, say that of the viola. The second record is then played while he records it together with his rendition of the second violin part, and so again until all the parts of the quartet have been accumulated. If the quality of the recording can be made such that the music does not lose appreciably by successive re-recordings, the only limitation on any performer who wishes to make a full orchestral rendition by himself should be his own virtuosity! Of course there is also the less pleasing possibility that an amateur tenor might equally well thus take advantage of the wonders of science and produce his own barbershop chords. TR

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